CRASHLESS CARS: Improving Auto Safety (*page 86*)

SCIENTIFIC AMERICAN



MAGIC and the BRAIN
page 72

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Secrets of Saturn's STRANGEST MOON

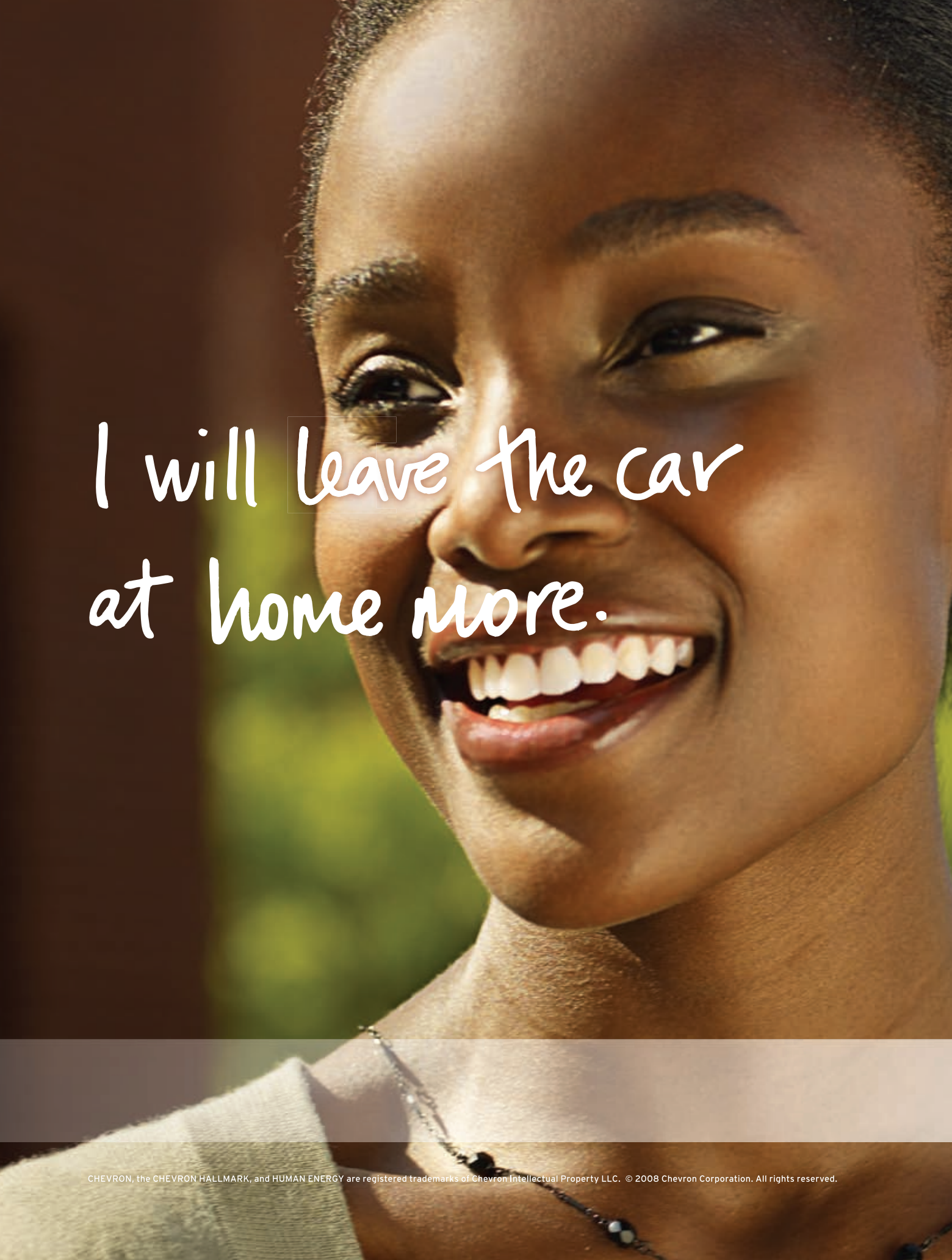
Icy Enceladus has active geysers—and perhaps a hidden sea that could harbor life

Cyberfraud
How to Foil Online "Phishing" Scams

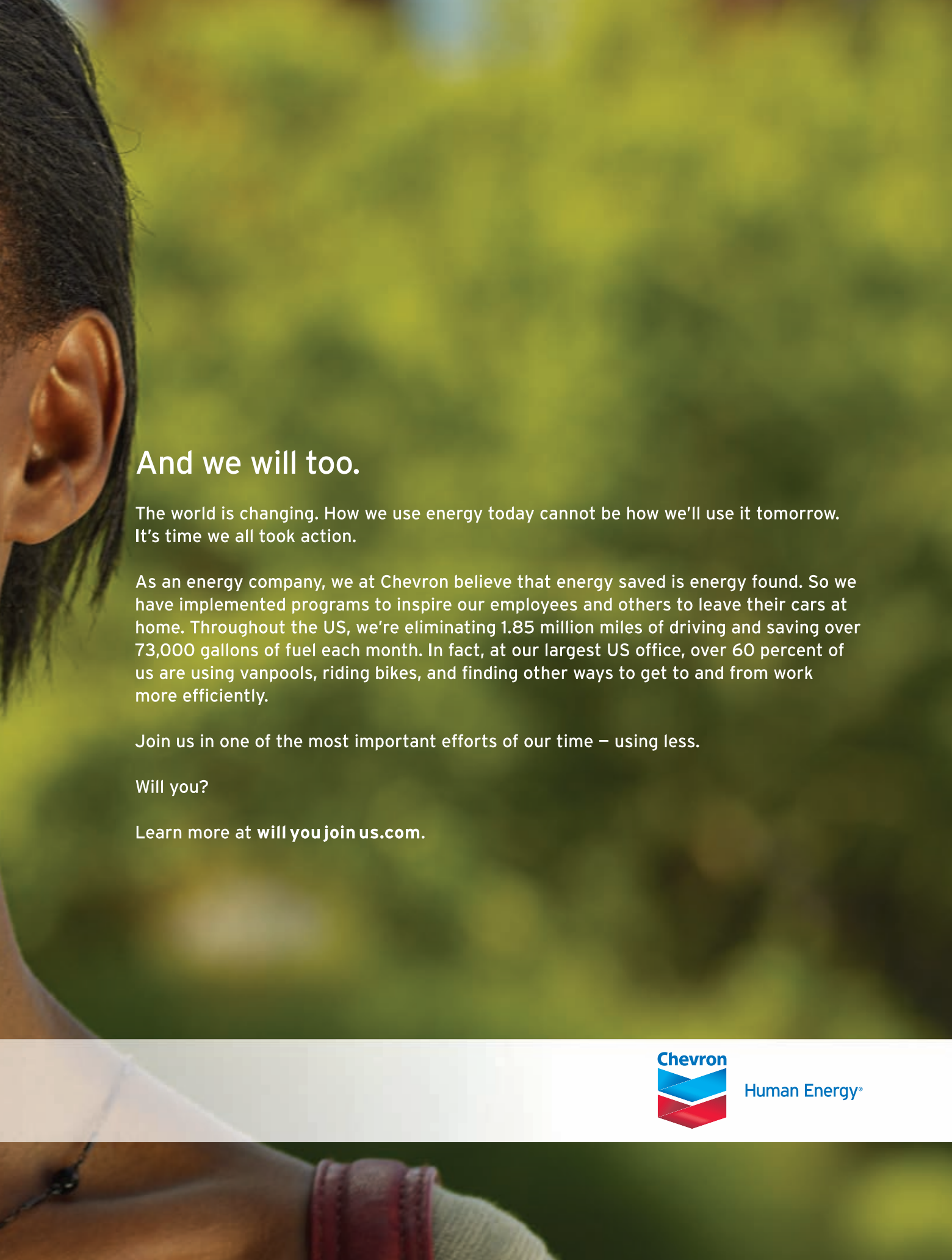
Triple Helix
Protein-DNA Molecule Points to Novel Drugs

Bigger Than Life
Winners of the 2008 BioScapes Photo Competition

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[1] WHO/UNICEF, 2004 data
[2] *FORTUNE*, March 2008
[3] *Ethisphere® Magazine,* June 2008

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PLANETARY SCIENCE

52 **The Restless World of Enceladus**

By Carolyn Porco

Scientists have known for decades that Saturn's sixth-largest moon is odd, but recently received images hint that its wrinkled landscape hides underground waters brewing with organic molecules. Could Enceladus be an icy cauldron for extraterrestrial life?

Image by Ron Miller





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By Peter E. Nielsen

Peptide nucleic acid, a synthetic hybrid of protein and DNA, could form the basis of a new class of drugs—and of artificial life unlike anything found in nature.

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By Susana Martinez-Conde and Stephen L. Macknik

Magicians have been testing and exploiting the limits of cognition and attention for hundreds of years. Neuroscientists are just beginning to catch up.

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The 2008 Olympus BioScapes Competition recognizes the year's greatest achievements in light microscopy.

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By Steven Ashley

Next-generation safety technology could give us vehicles that are difficult to crash—and eventually may not need drivers at all.







ON THE COVER

If astronauts ever visit Enceladus, they could witness the active geysers at its south pole, as imagined here by artist Ron Miller.

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BIOLOGY

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By Nancy B. Simmons

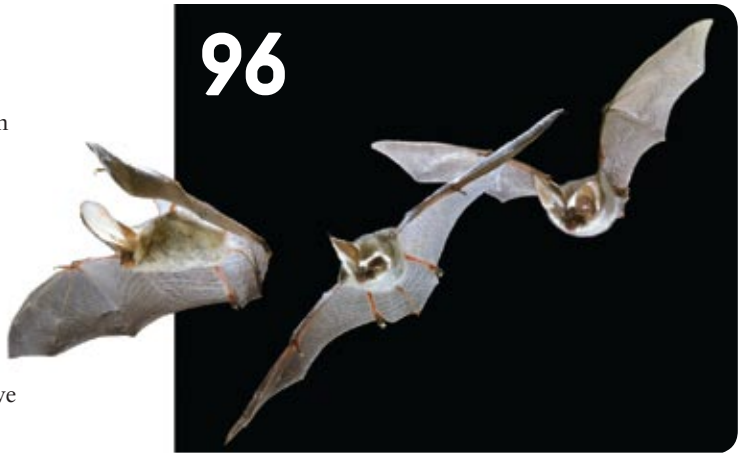
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IN-DEPTH REPORT: FUTURE OF THE POLES ▼

Who will rule the poles? A look at the Arctic landgrab for oil, the opening of the Northwest Passage and the potential end to the Antarctic treaty.
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MITSUAKI IWAGO *Minden Pictures*

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New evidence shows that women pass along more genes to kids than men do—and that males historically have fathered children with several women.

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Growing Urban Areas in Africa Helped to Spread HIV More Than a Century Ago
The most pervasive global strain of HIV began spreading among humans between 1884 and 1924.

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The Sticky Science of Gecko Toes
Artificial adhesive microfibers that do not lose their tackiness seem to imitate the structures with which a wall-climbing lizard clings to wet surfaces.

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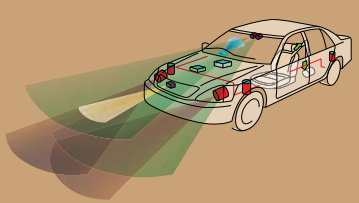
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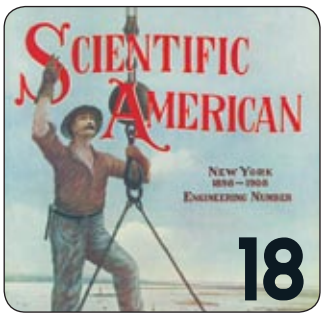
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The PC becomes a microscope: focusing up and down, zooming in and out, viewing fluorescence...

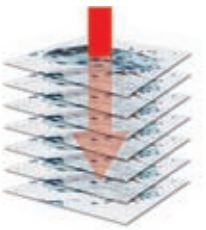


On her personal computer, without need of a microscope, a researcher analyzes a fluorescence-stained section of mouse kidney. This "digital slide" was scanned from an original glass slide by Hamamatsu's *NanoZoomer Digital Pathology* system.

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These digital slides can also include *location guides* to direct the viewer to a specific point of interest—a very valuable feature, especially in research areas such as drug development, gene expression and protein localization.

NanoZoomer Digital Pathology: one more way Hamamatsu is opening the new frontiers of Light.

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The Frontiers of Light

Beacons in the Night

When this world has you down, try looking at it from another one



Forty years ago, in December of the troubled year of 1968, astronauts Frank Borman, James Lovell and William Anders piloted the *Apollo 8* spacecraft into orbit around the moon, the first humans ever to circle any globe but our own. From that unique vantage, they sent back the iconic photograph (taken by Anders) shown below, known as "Earthrise." It unforgettably captured the fragile beauty of our living planet as it hovered in stark contrast over the arid sterility of the lunar horizon: a precious droplet of life—perhaps the only one we could ever know—in the velvety darkness.

For a world torn by conflicts over an unpopular war and other social upheavals, that photograph was a timely reminder of how inextricably united the fates of everything and everyone on Earth were. Indeed, the image is widely credited with having energized the environmental movement.

The Cassini spacecraft swinging through orbits around Saturn and its satellites has been sending back extraordinary pictures of its own, particularly from the moon Enceladus, and if they are less famous among most of the public, they may be no less inspirational to planetary scientists. In some respects, what Cassini sees is the inverse of what the *Apollo* astronauts did. Saturn is not a modest, life-bearing planet like Earth; it is a gaudy, frozen colossus decked out in a shining hoopskirt of rings.

More important, though, Enceladus is not a dead, dry bone of a moon. Cassini's evidence proves that Enceladus—seemingly against all odds—is a tectonically active world that sprays geysers of moisture from deep parallel fissures at its south pole. In fact, Saturn's feistiest satellite may contain an underground ocean's worth of water. Furthermore, spectroscopy shows that spouting water vapor is a soup of organic compounds. Enceladus thus flies into the elite ranks, alongside Mars, Titan and Europa, of the most promising places in our solar system to look for extraterrestrial life. NASA scientist Carolyn Porco, who oversaw imaging for the Cassini mission, explains the science arising from the spacecraft's latest discoveries, beginning on page 52.

It is wishful thinking, but perhaps the images from Cassini could be a message of hope for our time. Like 1968, 2008 is wracked by political turmoil and war. Epic economic disaster spilling out of the banking crisis has cast a pall over ambitions, both personal and national. But if "Earthrise" reminded us that we are all in this together (and by all means, let us not forget that), then Cassini and Enceladus are proof that beyond our immediate strife, the universe beckons and dares us to a more glorious future. Earth is still rising. ■

JOHN RENNIE
editor in chief

***APOLLO 8* first observed this sight.**



FLYNN LARSEN (*Rennie*); NASA (*"Earthrise"*)

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Water Cycle ▪ Fighting Hunger ▪ Migraine and Aura



AUGUST 2008

"To create effective long-term assistance for the poor worldwide, you must first target aid to support government policies that promote family planning and responsible procreation."
—*Ed Middleswart* PENSACOLA, FLA.

Water, Water Everywhere

Thank you for Peter Rogers's timely article on the increasing threat to freshwater resources, "Facing the Freshwater Crisis." I was, however, disappointed in the headline "Running Out of Water" and accompanying graphic on the cover. I speak frequently to the public about water and attempt to explain the hydrologic cycle. There are several bits of information that people have consistently told me were new to them, including that the cycle works on a global scale, that so little of the planet's water is readily available for human use and that the total amount of water has been relatively stable for eons. Unfortunately, because many people do not well understand the global, cyclical nature of our water system, they believe that water is literally disappearing. We need to consistently emphasize that water availability is decreasing not because the amount of water has changed but because we are placing greater demands on the resource.

Kristan Cockerill
Appalachian State University

Starvation Solutions?

In addressing responses to hunger in "developing nations," particularly in Africa, in "We Can Do More" [Perspectives], the editors advocate more effective aid programs (with policies to better ensure that aid reaches the poor, results in improved roads and farmer education, and affords better seeds, soil conditioning, irrigation, and so on), along with the eventual introduction of genetically modified organisms (GMOs). But these steps taken alone will only exacerbate the long-term conditions of poverty, deprivation and ecological catastrophe. The editors leave out an essential part of improving human welfare in a sustainable manner: control of population growth. To create effective long-term assistance for the poor worldwide, you must first target aid to support government policies that promote family planning and responsible procreation.

Ed Middleswart
Pensacola, Fla.

GMOs are not the solution to Africa's hunger. The editors' support of their use is based on the faulty premise that there is not enough food to feed the world and if only we could increase crop yields, people would not starve. Hunger is primarily a political and economic problem. The original green revolution was an overall failure for the poor throughout the world, and I have little hope for a new GMO-based green revolution. Patented seeds and the chemical pesticides and fertilizers they require benefit the large agribusinesses and not the hungry of developing countries.

Catherine Clarkin
Long Beach, Calif.

Aura of Mystery

"Why Migraines Strike," by David W. Dodick and J. Jay Gargus, claims that 30 percent of migraine sufferers experience an aura (illusions of sparks and lights, of-

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ten followed by blind or dark spots in the same configuration), whereas 100 percent experience headache. For the past 30 years I have experienced the aura once or twice a year. But I never get a headache.

David E. Ross
Oak Park, Calif.



AURAS, visual illusions sometimes associated with migraine headaches, take different forms. Many patients have sought to represent them artistically.

THE AUTHORS REPLY: *As many readers have suggested, aura symptoms may occur without headache. With increasing age, it is not uncommon to retain the aura but lose the headache or to develop aura symptoms without a prior history of headache. This phenomenon has been referred to as "late-life migraine accompaniments" or "migraine equivalents." The International Headache Society recognizes it as "typical aura without headache" and notes that some individuals, primarily men, only ever experience the aura.*

Although the reasons for the dissociation of aura and headache are unclear, several facts are worth noting: First, aura may occur with primary headache disorders besides migraine, and an aura can occur in patients with structural brain lesions. Second, the tendency to experience aura may be inherited as a trait that is distinct from the inherited tendency to experience recurrent attacks of migraine headache and its other associated symptoms.

The reason aura is more common in migraine sufferers (30 percent) than in the general population (1 to 2 percent) may be that the physiological consequences of one trigger the symptoms of the other when the two traits coexist. For example, cortical spreading depression (CSD) can activate trigeminal pain fibers and may trigger a migraine headache in migraine sufferers. In those not predisposed to migraine, CSD may lead to a mild nonmigraine headache or to no headache. Conversely, the putative brain stem generator for migraine may generate changes in metabolic activity of cortical neurons and glia, altering cerebral blood flow, which may trigger aura symptoms in an individual predisposed to CSD. The reason for aura symptoms' connection with age is unknown. Future research will, we hope, unravel this mystery.

Benefits to Burning?

"The Puzzling Inferno," by Keren Blankfeld Schultz [News Scan], discusses the finding that suppressing forest fires reduces carbon sequestering because frequent fires favor the growth of more mature trees, which store carbon more effectively. The story refers to prescribed fires as a solution, but other news media have reported the severe health effects of smoke from this year's wildfires. Frequent harvesting of immature trees and dead debris would also promote growth of mature trees. A good, technical assessment on the costs and benefits of forest burnings is sorely needed.

Dick Windgassen
Venice, Fla.

ERRATUM "The Puzzling Inferno," by Keren Blankfeld Schultz [News Scan], incorrectly describes the physical characteristics of trees. The measurements of 90 centimeters and between 10 and 30 centimeters refer to the diameters of the stems, not the heights. The article also states that larger trees are often the victims of drought partly because they require more oxygen. There is currently no evidence linking oxygen requirements to drought susceptibility.

CLARIFICATION "A Glimpse of the Past" [Updates] reports that FUNAI, Brazil's National Foundation for Indigenous Peoples, had used a low-flying airplane to photograph an indigenous tribe in Amazonia that had never been contacted by the modern world. Although the tribe is not known to have been contacted, José Carlos Meirelles of FUNAI has admitted that its existence was already known and that he sought to photograph the group to create publicity about the existence of such tribes in the area and to thereby protect their habitat from the threat of logging.

Letters to the Editor

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Letters may be edited for length and clarity. We regret that we cannot answer each one. Join the discussion of any article at www.SciAm.com/sciammag

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Universal Behavior ▪ Airplane for Enthusiasts ▪ Candle in the Dark

Compiled by Daniel C. Schlenoff

DECEMBER 1958

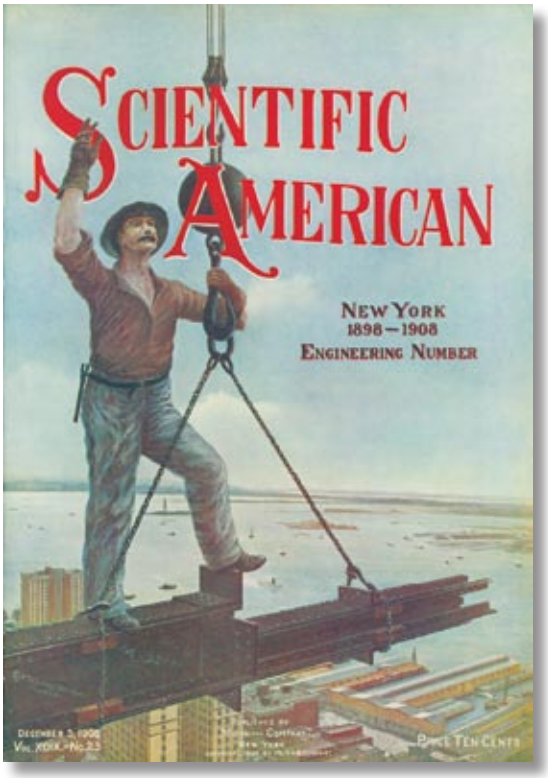
EVOLUTION OF BEHAVIOR—"But is it not possible that beneath all the variations of individual behavior there lies an inner structure of inherited behavior which characterizes all the members of a given species, genus or larger taxonomic group—just as the skeleton of a primordial ancestor characterizes the form and structure of all mammals today? Yes, it is possible! Let me give an example which, while seemingly trivial, has a bearing on this question. Anyone who has watched a dog scratch its jaw or a bird preen its head feathers can attest to the fact that they do so in the same way. A bird also scratches with a hind limb (that is, its claw), and in doing so it lowers its wing and reaches its claw forward in front of its shoulder. One might think that it would be simpler for the bird to move its claw directly to its head without moving its wing, which lies folded out of the way on its back. I do not see how to explain this clumsy action unless we admit that it is inborn. —Konrad Z. Lorenz"

[NOTE: Lorenz shared the 1973 Nobel Prize in Physiology or Medicine with Nikolaas Tinbergen and Karl von Frisch.]

ROBO TEACHER—"Can teaching be mechanized? B. F. Skinner, Edgar Pierce Professor of Psychology at Harvard University, believes that it must be if the rising worldwide demand for education is to be met. He has designed and built a number of 'teaching machines' which not only present material to the student (as do conventional audio-visual teaching aids) but continually test the student on the information he is acquiring. Skinner and his associates have used machines of this type in teaching part of a course in human behavior to nearly 200 Harvard and Radcliffe College undergraduates."

DECEMBER 1908

DEMOISELLE—"The noted Brazilian experimenter Santos Dumont has brought out once more the tiny aeroplane with which he made some experiments last spring. To give his monoplane good transverse stability, Santos Dumont has placed the two wings at a slight dihedral angle and has located his seat and the motor about 3 feet below. This brings the center of gravity well below the line of support. The spread of the wings is but 16.4 feet. On account of the small size of this monoplane (which he has christened 'Demoiselle'), Santos Dumont was able to carry it from Paris to St. Cyr on the rear of an automobile."



BUILDING BRIDGES—engineering the connections between an island and its people, 1908

ENGINEERING A CITY—"The problem of transportation in the city of New York is rendered extremely difficult and costly by the fact that 2,000,000 of the people live upon, and as many more daily enter or leave, a long, narrow island, which is separated from the mainland by broad and deep rivers. To overcome this isolation, public and private enterprise has built, during the past decade, no less than fourteen tunnels and three of the greatest long-span bridges of the world."

More images of these engineering feats are available at www.SciAm.com/dec2008

DECEMBER 1858

LIGHT THE WORLD—"Candles were among the earliest inventions of the fathers of our race, and despite burning fluid, gas and coal oil, still keep their place as light-givers—a luxury to the rich—a blessing to the poor. However, we must say that the candle is a greasy article, and much given to guttering, and wants snuffing very often; or rather did, for we wish to notice an invention which prevents these evils. A method has been patented of indurating or hardening common candles so that they are in every way equal to spermaceti or the highest priced varieties. The indurated coating, being fusible at a much higher temperature than the tallow, causes the candle to burn with a beautiful cup-shape and prevents guttering."

ELEPHANTS—"The Ceylon *Observer* contains an account of some brick-making works recently visited by Sir Henry Ward. The works, which turn out about 20,000 bricks a day, are only six miles from Colombo. The clay for brick-making is prepared by elephants. The wild and tame work together, and both attempt to shirk their work by endeavoring to put their feet in old footprints, instead of in the soft, tenacious, untrodden mud."

SCIENTIFIC AMERICAN, VOL. XCIX, NO. 23; DECEMBER 5, 1908

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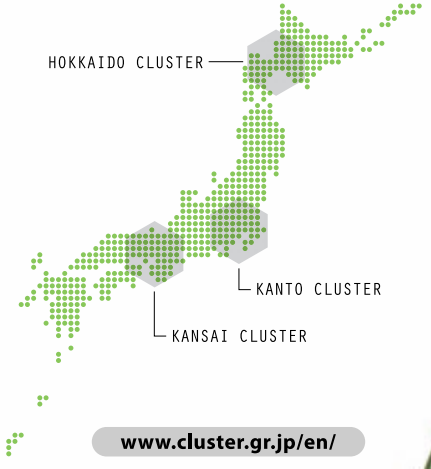
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Japan's biotechnology industry—the world's second largest behind the U.S.—is in a period of transformative growth. Targeting biotechnology as a key industry for development, the Japanese government has launched policy initiatives to encourage growth and investment in bio-industry clusters around the country. These clusters are home to a growing number of world-class business ventures whose innovation has made Japan the world leader in several bio-industries. For example, Evec, a start-up in the Hokkaido Bio Industry Growth Strategy, has developed a method for producing fully human monoclonal antibodies in the human body. Their highly efficient production method enables the company to meet the high demand of pharmaceutical companies worldwide for a consistent supply high-quality antibodies. Breakthrough technologies such as this make Japan's biotech industry a fertile environment for foreign investment.

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Japanese biotechnology market growth

Source: 2008 Bio Business Market, *Fuji Keizai, Inc.*
Yen-to-dollar exchange rate based on IFS data from the IMF

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Transgenic Guidelines ▪ Midsize Black Holes ▪ HIV Century ▪ Neandertal Fishing

Edited by Philip Yam

Rules for Genetically Engineered Animals

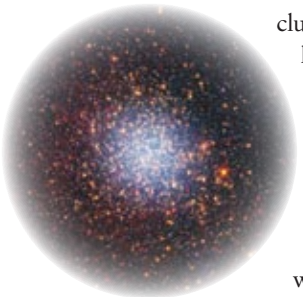
After years of anticipation, the U.S. Food and Drug Administration released in September preliminary guidelines for genetically engineered animals [see "Does the World Need GM Foods?"; SciAm, April 2001]. The agency, which deemed that cloned meat poses no extra risk, wants to regulate engineered animals as it does drugs. Producers would have to substantiate claims and demonstrate safety. Consumer groups complain that the draft sets no provision for labeling and that safety trials can be done behind closed doors, as is the case for drug applications. Public comment on the draft ended in mid-November, and the FDA was to issue its final guidelines shortly thereafter.



FEATHERLESS ROOSTER and other transgenic animals would be regulated like drugs.

No Middle Ground

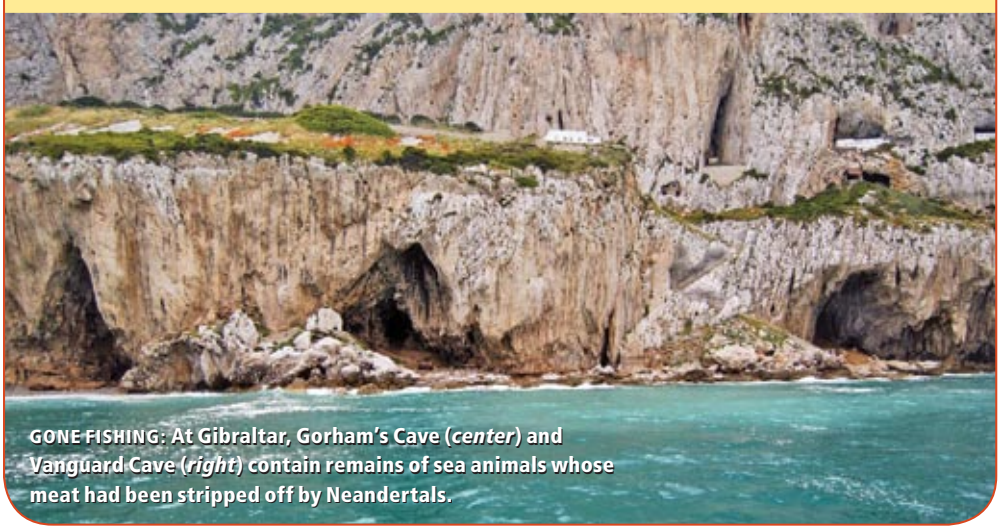
Astronomers know of the giant black holes at galactic cores and the comparatively lightweight versions that form when stars collapse. But what of black holes in between? [See "Hole in the Middle"; SciAm, April 2001.] Such midsize versions now seem to be especially rare. Their best hiding places were thought to be at the centers of dense clumps of stars called globular clusters. Resembling miniature galaxies, these clusters should have matching-size black holes, scientists reasoned. A recent examination of globular cluster RZ2109 (*left*), however, reveals that it possesses a small black hole. Its presence implies that RZ2109 does not have a medium black hole, which would have pulled in the small one. The findings hole up in the August 20 *Astrophysical Journal Letters*.



—Charles Q. Choi

Resourceful Neandertals

Our Ice Age cousins the Neandertals were hardly the doltish brutes that scientists once believed them to be [see "Who Were the Neandertals?"; SciAm, April 2000]. This realization has raised the question of why they lost out to *Homo sapiens*. Some experts have argued that *H. sapiens* outcompeted them by exploiting a wider variety of foods than did the Neandertals, who seemed to have subsisted mostly on large, dangerous land mammals such as woolly rhinos. But researchers writing in the September 23 *Proceedings of the National Academy of Sciences USA* report that Neandertals at two coastal sites in Gibraltar—Vanguard Cave and Gorham's Cave—routinely dined on mollusks, fish, seals and dolphins for tens of thousands of years. With Neandertals apparently able to formulate hunting and gathering strategies as advanced as those of the modern humans who lived after them at these sites, the secret of *H. sapiens* success is more mysterious than ever. *—Kate Wong*



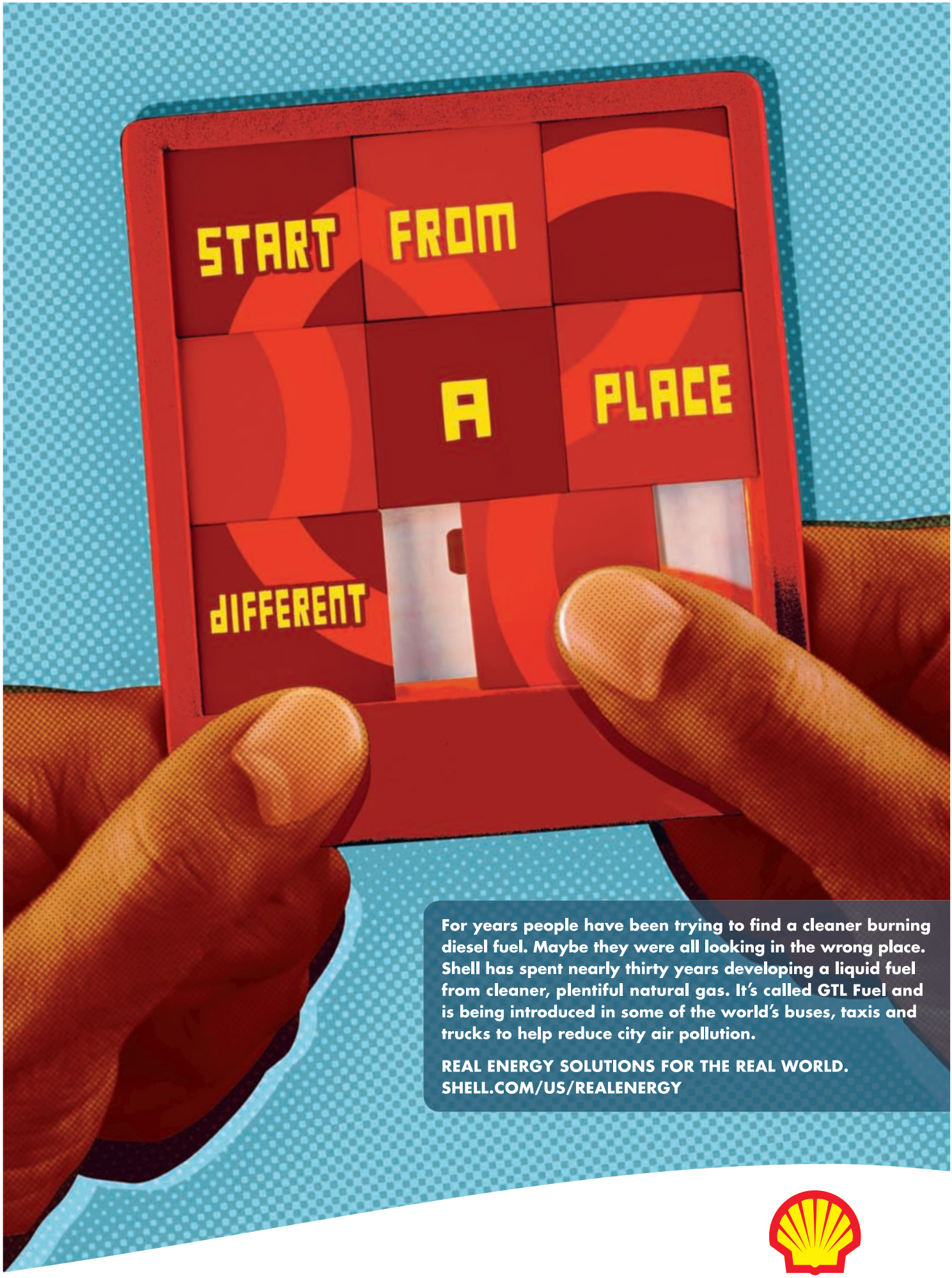
GONE FISHING: At Gibraltar, Gorham's Cave (*center*) and Vanguard Cave (*right*) contain remains of sea animals whose meat had been stripped off by Neandertals.

Longtime Companion

A lymph node biopsy taken in 1960 from a woman who lived in what is now Kinshasa, Democratic Republic of the Congo, contained traces of the HIV-1 genome. Comparison with existing HIV sequences suggests that HIV surfaced in 1908, pushing back by a decade an earlier estimate based on an infected blood sample collected from the same city in 1959. The finding, in the October 2 *Nature*, suggests that trade routes may have contributed to the emergence of the virus, which most likely originated among chimpanzees in Cameroon, hundreds of kilometers from Kinshasa. Understanding HIV's origin could lead to better AIDS therapies [see "HIV 25 Years Later: The Big Challenges"; SciAm, November 2008].

MOSHE MINOR *Getty Images (chicken)*; NASA/JPL-CALTECH/NOAO/AURA/NSF (*black hole*); COURTESY OF CLIVE FINLAYSON *Gibraltar Museum (caves)*

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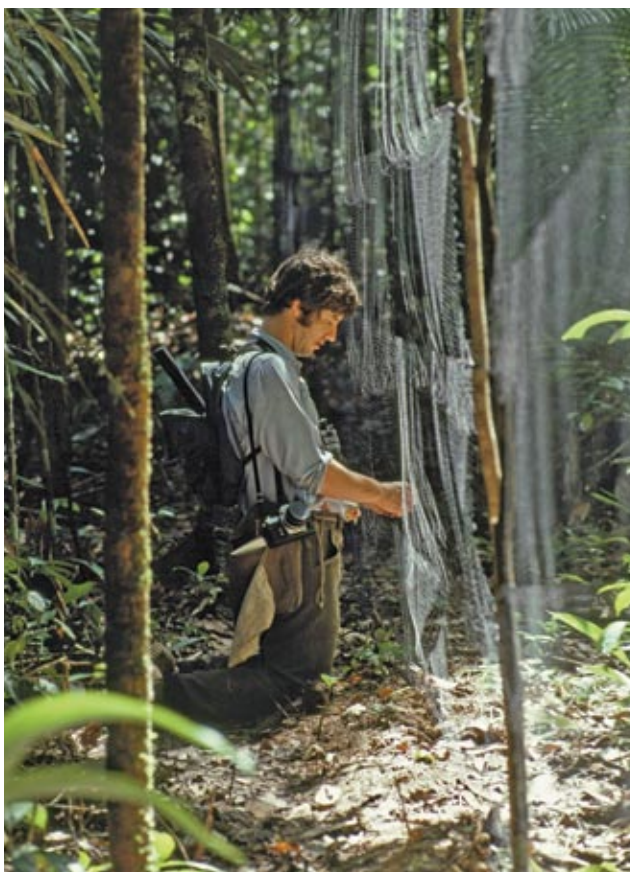
As nations view their flora and fauna as commodities, science suffers BY LINDA BAKER

For the past three years, botanist Vicki Funk of the Smithsonian Institution has been trying, unsuccessfully, to transfer select leaf specimens from Brazil to the U.S. National Herbarium for identification. Comparing closely related plants "is the bread and butter of systematics," she explains. "We need stuff from other places." But as biodiversity becomes a valuable commodity, developing countries have complicated efforts to collect and analyze biological samples, Funk says: "It doesn't matter if you're an academic, not a drug company. You're treated the same."

In 1992 the twin goals of the United Nations Convention on Biological Diversity, signed by more than 150 countries, were to preserve biodiversity and to ensure tropical nations were compensated for any "genetic resources" leading to drug discoveries for developed nations. But even as those goals were reaffirmed at a conference held this past spring in Bonn, Germany, scientists continue to criticize policies stemming from the convention. The claim is that the international agreement, which gave countries ownership of plants and animals inside their borders, is hindering tropical research and conservation, not facilitating them.

"The biodiversity convention made the argument that plants and other microorganisms were sovereign entities that needed to be treated with commercial transaction approval," remarks Josh Rosenthal, a deputy director at the Fogarty International Center at the National Institutes of Health. As a result, "the ethos of global scientific collaboration has changed," and the conditions for research have become more challenging.

Western scientists are not alone in their analysis. The January 2008 *Current Science,* a journal published by the Indian Academy of Sciences, included an article decrying the "shackles" Indian biodiversity law imposes on native scientists—such as prohibiting them from placing specimens in international repositories. "We need to highlight the importance of sharing biological resources among nations," says co-author K. Divakaran Prathapan, an entomologist at the University of Kerala. The article was entitled "Death Sentence on Taxonomy."



JAMES P. BLAIR *National Geographic/Getty Images*

CONTROVERSY OVER COLLECTION: Taking biological samples from Brazil's rain forest and other areas poses a challenge for global science because of an agreement that gives countries ownership of plants and animals within their borders.

Of course, a history of abuses means poorer countries have every reason to question scientific work conducted on behalf of industrial countries. In 1995, for example, the U.S. granted a patent for turmeric to two doctors at the University of Mississippi—even though the anti-inflammatory properties of the herb had been documented as part of the Indian Ayurvedic tradition for centuries. "It was the most ridiculous patent I've ever seen," exclaims David Gang, a professor of plant sciences at the University of Arizona.

After protests erupted in India, the patent was revoked. But so were opportunities for research—and the public benefits that go along with it. Gang says he would like to see a global consortium of labs to sequence the genome for turmeric—modeled after the successful International Rice Genome Sequencing

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Project, which was completed in 2004. "But there is no possibility of collaboration with anyone in India," he laments.

Designed to prevent exploitation, proprietary botany laws block opportunities for developing countries to form their own scientific infrastructure, argues Art Edison of the University of Florida, who is forming a project to analyze soil activity in a Peruvian reserve. "The problem is, people are so focused on the remote possibility of a major drug discovery that they don't deal with the practical benefits of attracting U.S. research dollars, such as helping train [native] students and set up labs," he says. These jobs in turn help supplant logging and other destructive practices.

Peru and its neighbors have some of the strictest rules in the world against collecting and transferring biological material. "When I first entered into the project, I was focused on the science," Edison recalls. "The great fear of 'biopiracy' was a complete eye-opener."

There are some positive developments. Prodded by its own scientists, the Brazilian government implemented a system last year expediting licenses to collect biological material for scientific research—although applications involving conservation areas or the export of biological samples were excluded from the new rules. Some Western research institutions, such as the New York Botanical Garden, have put together detailed protocols outlining benefit-sharing opportunities for host countries that have helped facilitate scientific research and exchanges.

But as nations renew their commitments to the biodiversity convention, "many are tightening up regulations," says Phyllis Coley, a plant sciences professor at the University of Utah. Panama, for example, used to have one of the most liberal attitudes toward foreign scientists but is now drafting more restrictive legislation, she states. Framing biodiversity in terms of political boundaries and sovereign intellectual property was supposed to encourage preservation, the Smithsonian's Funk says. "It's backfired," she declares. "We have to conserve life on its own terms."

Linda Baker is based in Portland, Ore.

PERCEPTION

Into the Uncanny Valley

Researchers take a closer look at creepiness in the almost human BY GARY STIX

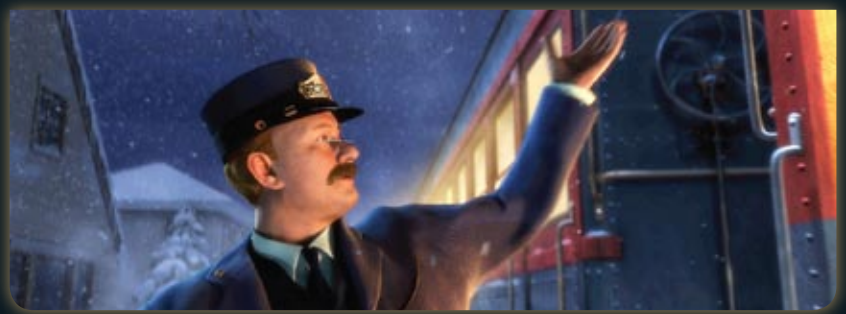
The critically acclaimed television series *30 Rock* has one episode in which variety show host Tracy Jordan plans to create a pornographic video game. Frank Rossitano, a writer in this fantasy of what happens behind the scenes at a *Saturday Night Live*–like comedy show, informs Jordan that the game would surely flop because of something called the uncanny valley. He even produces a graph to demonstrate why failure is all but inevitable.

The uncanny valley has kindled debate among roboticists for more than 35 years—and more recently computer graphics jocks have joined this ongoing discussion about whether their creations will end up scaring people. Envisaged in 1970 by Japanese roboticist Masahiro Mori, the concept implies that whereas cartoonish or other abstract human figures draw immediate empathy, robots or animations that appear similar to humans (but not identical) provoke a sense of unease.

In an otherwise human-looking robot or animation, a stilted arm or eye movement—or perhaps a halting gesture in landing a kiss in Tracy Jordan's porn game—creates an eerie sensation. This feeling is represented by a sharp dip on a graph, an "uncanny valley" in which the observer's comfort level with the artificial character diminishes drastically. In Mori's

The Creepy Express

Hollywood is aware of the potential for the near human to alienate audiences. After working as a lead animator on *The Polar Express* (*below*), a movie criticized for its characters' high creep quotient, Kenn McDonald and his colleagues at Sony Pictures Imageworks watched the film about five times and, in subsequent projects, decided to animate the rapid, small eye movements called saccades. "If you get the eyes right, everything else is icing on the cake," McDonald says. Without invoking roboticist Masahiro Mori's uncanny valley specifically when designing characters, Pixar Animation Studios does not stray far from Mori's advice. "If your goal is to create realistic humans," says Pixar production designer Ralph Eggleston, "you run the risk of the audience being distracted when things aren't just right, instead of having people pay attention to the story."



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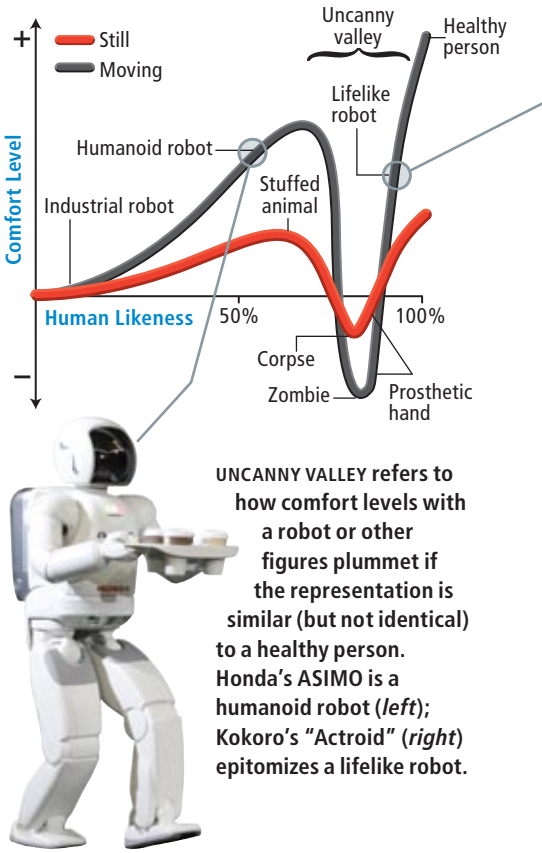
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NEWS SCAN



UNCANNY VALLEY refers to how comfort levels with a robot or other figures plummet if the representation is similar (but not identical) to a healthy person. Honda's ASIMO is a humanoid robot (*left*); Kokoro's "Actroid" (*right*) epitomizes a lifelike robot.

view, a full ascent out of the valley occurs only when robots become indistinguishable from humans.

Mori recommended that robot designers should avoid queasy reactions altogether by building robots that are not human facsimiles, an idea that has sometimes been adopted as a de facto design principle among roboticists. Despite his warnings, designers have ignored his entreaty. They can now build robotic heads or bodies covered by skin realistic enough to at least briefly fool humans [see "Android Science," by Tim Hornyak; SCIENTIFIC AMERICAN, May 2006]. The silicone layer that produces this convincing effect has, in fact, become the stuff of $6,500 sex dolls.

As robots have begun to catch up with their masters, researchers have started to ask whether the uncanny valley actually exists. Mori's graph was not based on experimental data—and recent studies mapping out responses to humanlike robots have produced conflict-

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LUCY READING-IKKANDA (*graph*); LUIS GENE *AFP/Getty Images (ASIMO)*; KOICHI KAMOSHIDA *Getty Images (Actroid)*

ing results. David Hanson of Hanson Robotics in Richardson, Tex., has found that people's varying reactions to an anthropomorphic robot or animation does not depend on the level of realism; instead it hinges on whether a robot's appearance has an inherently creepy aesthetic. Frankenstein's monster elicited a repellent reaction not because of an overwhelming human likeness but simply because the monster was just plain ugly. Intentionally steering clear of realistic human forms, as Mori suggested, offers no protection. "A Disney villain or cartoon can be very abstract and still unsettling," Hanson says.

The uncanny valley may not be an exact representation of people's perceptions of the bizarre, but a few studies provide some basis for Mori's intuitions. As researchers have conducted experiments in search of the valley, they have found that as a robot or animation grows more realistic, the latitude that designers have to change the size of, say, the eyes or the head decreases greatly. "As you come closer to building robots that look more human, there is a narrowing of the range of forms that would still be acceptable," says Karl MacDorman, an Indiana University professor, who attributes these reactions to innate aversions to traits that might be linked with ill health or lack of fertility.

The science of aesthetics is about to grow more complex as humans choose to morph themselves. "How will we behave when people are not quite right, not because of behavioral or physical problems but because of behavioral or physical enhancements?" asks Jamais Cascio, a consultant to the Institute for the Future. Prosthetics and genetic engineering may affect appearance; even now the

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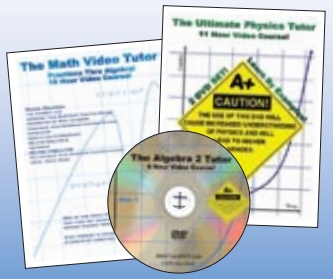
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work of cosmetic surgeons can yield an unease reminiscent of the valley. One blogger placed Madonna—after requisite face-lifts, Botox injections and photo retouching—at the exact spot on Mori's graph once occupied by the handicapped, which is near the bottom of the valley (but usually replaced today by a prosthetic hand for political correctness). Robots, humans, who knows, maybe even Mickey Mouse, all appear headed for Mori's big pothole.

OCEANOGRAPHY

Stations in the Seas

Taking shape: permanent underwater observatories BY BARBARA JUNCOSA

To study the oceans, scientists rely on a network of orbiting satellites and surface vessels. But space-borne instruments cannot penetrate the inky surface, and ship time remains expensive and scarce. These frustrations, compounded by the growing need to understand global changes, have spurred researchers to design the Ocean Observatories Initiative (OOI)—a $330-million project that promises to herald the next generation of oceanographic study.

At the heart of the OOI lies an infrastructure expected to operate for 25 to 30 years. Truly comprehending the world's waters and how they react to climate change requires observations spanning decades, says Uwe Send, a physical oceanographer at the Scripps Institution of Oceanography in La Jolla, Calif. But because many important events happen suddenly, such as storms, red tides and earthquakes, permanent sensors must be ready to capture them.

The envisioned system combines stationary devices with mobile sensors. Moorings anchored to the seafloor will support upgradable instrument packages that move vertically along taut cables, measuring various conditions from the surface to the bottom. Autonomous underwater vehicles will glide outward



CEV AND JOHN DELANEY

DEPTH-DEFYING: Artist's conception of a seafloor laboratory examining pillars formed by hydrothermal venting on the Juan de Fuca tectonic plate in the Pacific Ocean. The Ocean Observatories Initiative plans to deploy such labs on the entire plate for real-time study.

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from these moorings along preprogrammed paths, capturing details about the physics, chemistry and biology of broad areas around the moorings.

Investigators plan to anchor three arrays in the polar regions, where climate change could dramatically impact ice formation and global ocean currents. Around Cape Cod, a similar array will monitor the ecosystems crucial to local fisheries for up to five years, after which the moorings will be moved to study other coastal ecosystems, including the Gulf of Mexico.

Perhaps the most ambitious aspect of the project is planned for the Pacific Northwest, where an entire tectonic plate—the Juan de Fuca plate—will be wired with sensors to monitor its movements and the resulting volcanic activity and earthquakes. Providing power and two-way communication, fiber-optic cables installed along the seafloor will allow scientists sitting in their laboratories to adjust measurements instantaneously as events unfold on the plate.

For the first time, investigators will be able to observe the extreme events that shape the planet in real time, remarks John Delaney, a physical oceanographer at the University of Washington. Through these robots, sensor packages and high-definition cameras, he adds, researchers will establish an unprecedented telepresence in even the most hazardous environments of the deep ocean.

Moreover, data from the networks will be immediately—and freely—downloadable via an "iTunes-like" interface, says Scripps geophysicist John Orcutt, who believes that the approach will encourage virtual labs to spring up across the Internet. In a field steeped in a culture of proprietary data, such open access could be hard to accept, notes Holly Given, director of the OOI at the Consortium for Ocean Leadership in Washington, D.C. The hope is, though, that data available to all will lead to novel algorithms for modeling changes to the oceans. Organizers also hope the readings, which could be used to create interactive games, will provide a window through which the public can learn about the oceans.

Although the OOI stems from a grassroots movement that started in the late 1980s, a sense of urgency now prevails if the U.S. hopes to stay at the forefront of oceanographic research. "In the past 10 years, almost all developed nations with the capacity to enter the oceans are doing it or getting ready to do it," Delaney states. In fact, Canadian researchers have already moved forward with plans to place sensors along the northern third of the Juan de Fuca plate, and China recently entered the fray with ambitious plans for observatories in its coastal waters.

The U.S. began preliminary work this past August—namely, mapping the seafloor of the Pacific Northwest to identify sites for fiber-optic cable installation. Actual construction could start in a couple of years, pending its expected inclusion in the National Science Foundation's 2010 budget. With permanent observatories under the sea, scientists could soon literally use their fingertips to tap into the ocean's secrets.

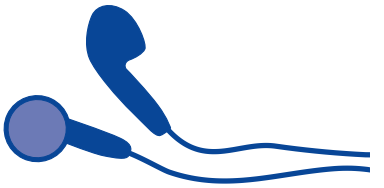
PHYSICS

Quantum Brinkmanship

New quantum weirdness found: balls that don't roll off cliffs

BY GEORGE MUSSER

A good working definition of quantum mechanics is that things are the exact opposite of what you thought they were. Empty space is full, particles are waves, and cats can be both alive and dead at the same time. Recently a group of physicists studied another quantum head spinner. You might innocently



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REFLECTED BACK: Just as the sea surface can reflect light waves back into the water, the edge of a table can reflect a quantum wave (describing a particle) back onto the table, preventing it from rolling off.

think that when a particle rolls across a tabletop and reaches the edge, it will fall off. Sorry. In fact, a quantum particle under the right conditions stays on the table and rolls back.

This effect is the converse of the well-known (if no less astounding) phenomenon of quantum tunneling. If you kick a soccer ball up a hill too slowly, it will come back down. But if you kick a quantum particle up a hill at the same speed, it can make it up and over. The particle will have "tunneled" across (although no actual tunnel is involved). This process explains how particles can escape atomic nuclei, causing radioactive alpha decay. And it is the basis of many electronic devices.

In tunneling, the particle can do something the ball never does. Conversely, the particle might not do something the ball always does. If you kick a soccer ball toward the edge of a cliff, it will always fall off. But if you kick a particle toward the edge, it can bounce back to you. The particle is like one of those little toy robots that senses the edge of a table or staircase and reverses course, except that the particle has no internal mechanism to pull off its stunt. It naturally does the exact opposite of what the forces acting on it would indicate. The researchers behind the analysis—Pedro L. Garrido of the University of Granada in Spain, Jani Lukkarinen of the University of Helsinki, and Sheldon Goldstein and Roderich Tumulka, both at Rutgers University—call this phenomenon "antitunneling."

STEPHEN FRINK

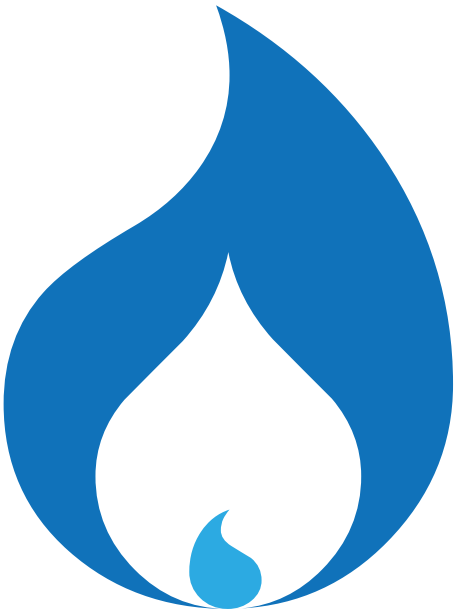
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In both cases, the explanation lies in the wave nature of particles, which in turn reflects the fact that a quantum particle generally has an ambiguous location. The wave describes the range of locations where it could be found. This wave behaves much like ordinary waves such as sound. Whenever any wave encounters a barrier that is not absolutely rigid, some of the wave will penetrate into the barrier, albeit with diminishing intensity. If the barrier is not too thick, the wave can reemerge on the other side. That is analogous to tunneling.

For antitunneling, the analogy is that whenever any wave encounters any abrupt change of conditions—even ones more favorable to its propagation—some of it will reflect back. Something similar happens when a scuba diver looks up and sees the sea surface acting as a mirror. To be sufficiently abrupt, the distance over which conditions change must be shorter than the wavelength (which for a particle is related to momentum). If the change is too gradual, the wave will simply go along, and the particle will act like a soccer ball after all.

Garrido and his colleagues undertook a numerical analysis to rule out the possibility that the phenomenon was an artifact of idealized assumptions. They also calculated how long a particle will tend to roll around the table before going over the edge; it gets longer the higher the table is. David Griffiths of Reed College, author of a widely used introductory quantum mechanics textbook (the second edition of which gives a version of antitunneling as a student exercise), calls it "a very sweet paradox." Physicist Frank Wilczek of the Massachusetts Institute of Technology says, "It's a solid analysis, and it points out an interesting phenomenon I hadn't been consciously aware of."

Antitunneling might have applications for building laboratory particle traps, describing nuclear decay or exploring the foundations of quantum mechanics, but its main appeal is to remind physicists how a nearly century-old theory has lost none of its capacity to surprise.



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COSMOLOGY

Deeper into the Void

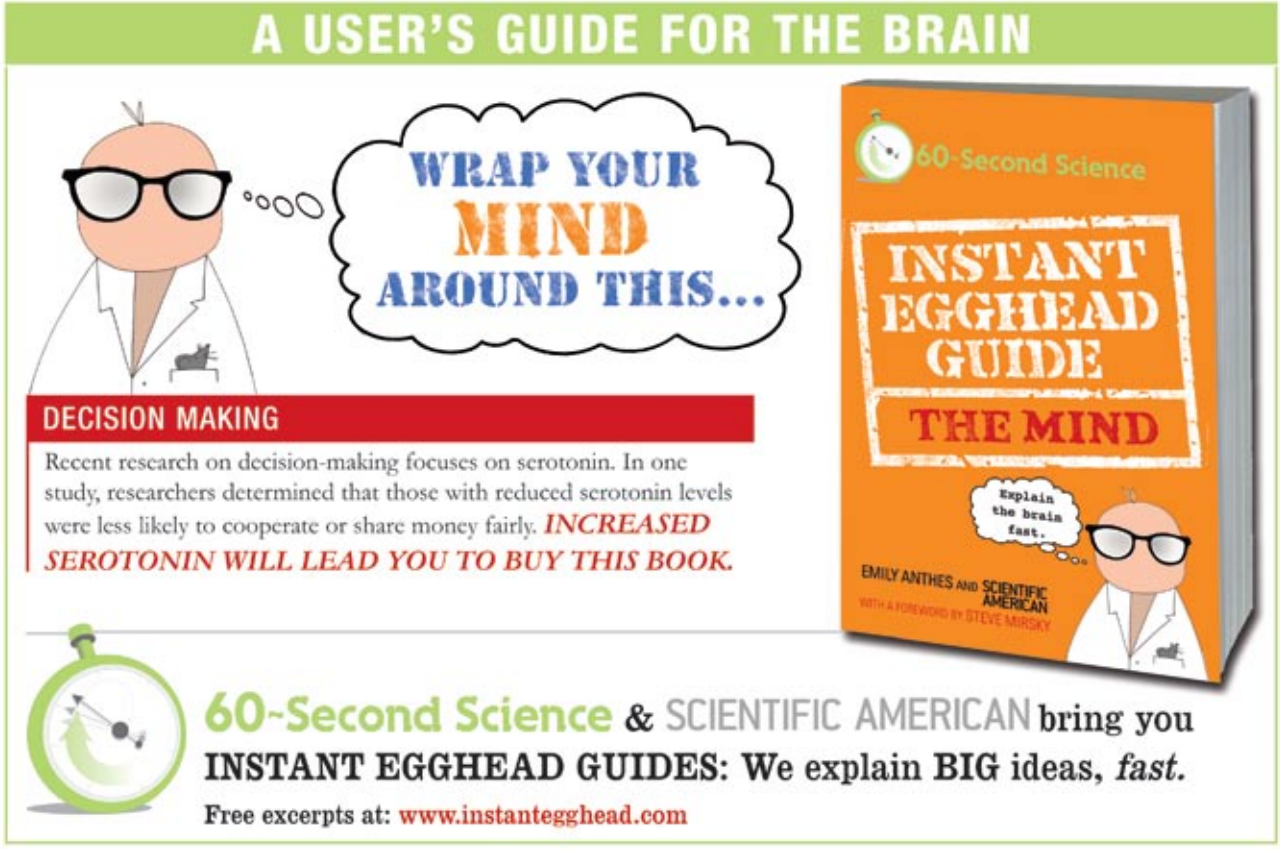
Planck mission promises to pierce inflation and other cosmic secrets BY DAVID APPELL

In a fitting irony, the static that once bothered scientists trying to tune in to the universe has turned out to be an incredibly rich source of information about it. Probing these signals over the past 40 years—known as the cosmic microwave background (CMB) radiation—scientists have dug out cosmological secrets that have revolutionized the field. Next, European scientists will spy on the relic photons with instruments of unprecedented detail, when they launch the Planck satellite in early 2009.

But the Planck mission won't be about putting the proverbial "one more number after the decimal." For the first time, it will probe the dynamics of the early inflationary universe. By sifting through the details of how the temperature of the early universe varied slightly in different directions, the many different models of inflation—the furious exponential expansion of space that took place around 10^{-35} second after the big bang—can be put to the test, as each makes its own unique predictions. The satellite will also look for evidence of primordial gravity waves, providing theorists with more data to apply to their ideas. And it will more accurately measure the densities of ordinary matter, dark matter and dark energy that occur in puzzling proportions in the universe (5, 23 and 72 percent, respectively).

After years of planning, construction and testing, "smiles are on all faces," says Jean-Michel Lamarre of the Paris Observatory, the instrument scientist for one of the satellite's two onboard specialized cameras called the High-Frequency Instrument. (The other is the Low-Frequency Instrument.) About the size of a family car, the Planck satellite will launch from French Guiana in tandem with the European Space Agency's Herschel Space Observatory. It should begin returning data in the summer and has a mission lifetime of 21 months.

The European Space Agency began planning the Planck mission in 1992, when NASA's Cosmic Background Explorer (COBE) satellite began sending back data

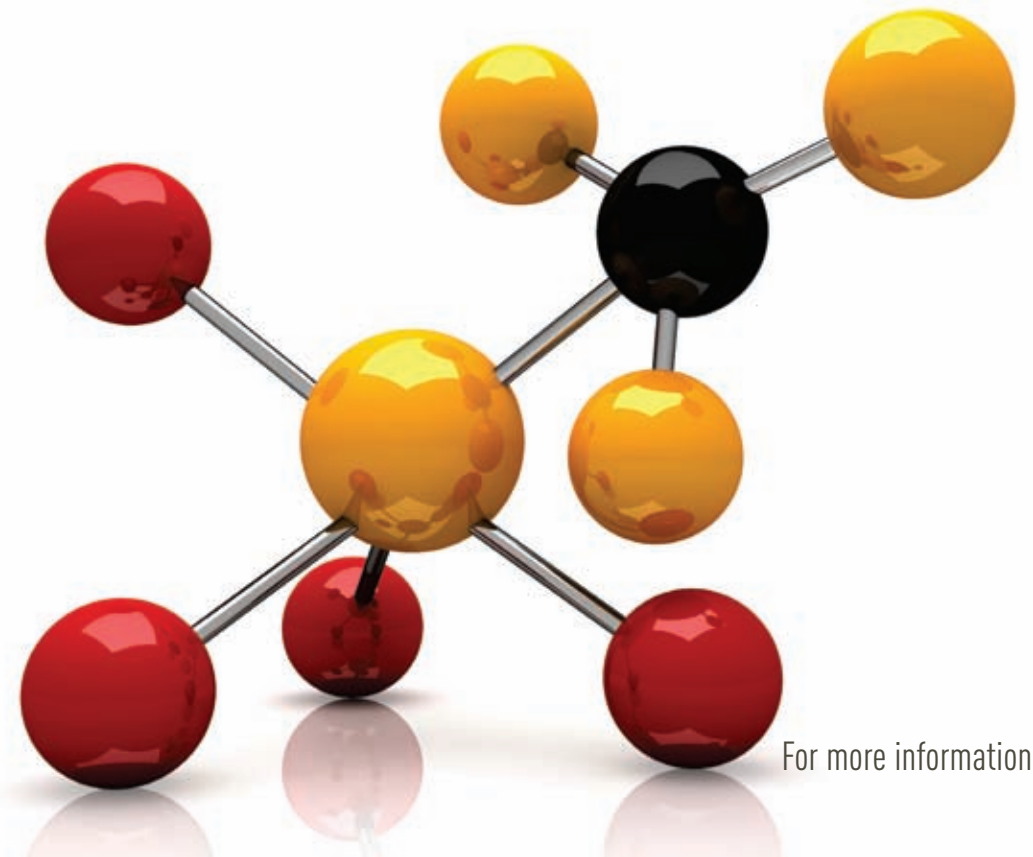


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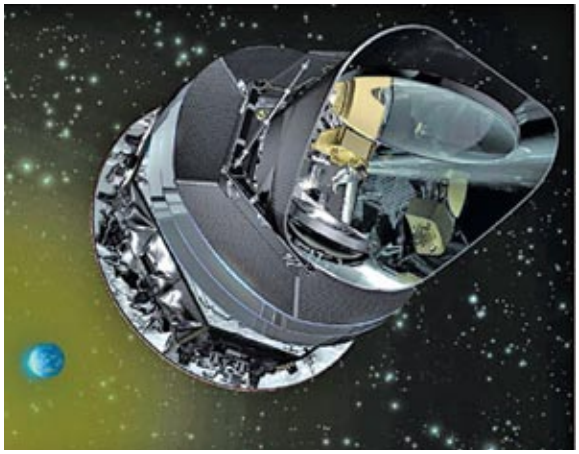


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on anisotropies in the CMB—subtle but definite fluctuations in the remnant background heat of the universe (–270.42 degrees Celsius, or 2.73 degrees above absolute zero). Evident at only 10 parts per million, these energy density fluctuations ultimately led to the development of structure in the universe—galaxy clusters and large voids between them—and their measurement uncorked a stream of findings about the big bang.

In 2003 the field took another leap forward when the Wilkinson Microwave Anisotropy Probe (WMAP) satellite looked at the CMB with 45 times more sensitivity. It gave scientists accurate measurements of the age of the universe (13.73 billion years), its rate of expansion (70.1 kilometers per second per megaparsec, where a megaparsec is 3.26 million light-years), and the proportions of the stuff making up the universe. WMAP confirmed the leading theory in cosmology, so-called lambda-CDM (cold dark matter), which is a universe governed by Einstein's theory of general relativity and dominated by gravity-repelling dark energy.

The Planck satellite will measure the fluctuations of the CMB to two parts per million, which is about three times better than WMAP did. And its two sophisticated cameras will gather light from nine frequency channels (WMAP had five, in a limited range) with noise lower by an order of magnitude.



DEEP STARE: Planck satellite, slated for an early 2009 launch, will measure the cosmic microwave background radiation.

"Planck will tell us fundamentally new things, complementary to WMAP," says Oliver Zahn of Lawrence Berkeley National Laboratory, who has been elbow-deep in the calculations that will turn Planck's raw data into cosmological parameters. "I'll be surprised if Planck is not as surprising as WMAP and the Hubble Space Telescope have been." WMAP can measure less than 10 percent of the information contained in the CMB temperature anisotropies and only a tiny fraction in the directional deviations of the CMB's polarization (the bearing of its electric and magnetic fields as it propagates through space). In contrast, Planck's full-sky view will measure essentially all the temperature information and a significant part of the polarization data.

The most exciting results could come from the so-called B modes of the polarization data, which have never been measured. The strength of the gravity waves predicted to be generated by the universe's inflationary phase determines the amplitudes of these B modes, so measuring them can pinpoint the best among competing models of inflation. Planck could, then, provide proof that the universe went through an inflationary phase and indicate the scale of the energy that drove it. "Of all the exciting science that we will do, this is the most exciting possible measurement of all," says Jan Tauber, the European Space Agency's chair of the Planck science team. And, as always, the best thing to come from Planck could be completely unexpected.

David Appell lives in Portland, Ore.

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ARCHAEOLOGY

No Accounting in Iraq

How badly damaged are the archaeological remains of ancient Mesopotamia? BY PETER BROWN

More than five and a half years into the Iraq War, the condition of archaeological sites and antiquities in Iraq remains a frustrating and contentious topic among archaeologists and art historians. Two surveys in the past year—one in northern Iraq in May, the other in the south in June—have persuaded some that the ongoing damage is far less extensive than most observers had believed. Yet with more than 10,000 registered sites and numerous other mounds of earth that may still conceal uncatalogued treasures from the "cradle of civilization," many archaeologists question whether the surveyed sites are representative of conditions elsewhere.

The report of the May survey, conducted by U.S. and Iraqi investigators, stated that "none of the sites showed signs of looting or extensive vandalism." Likewise, the June report, by a team of Iraqi and British archaeologists who visited eight southern sites, found little evidence of looting since the war began.

Nevertheless, the report of the Iraqi-British project cautioned that "it is difficult (and dangerous) to generalize" from the conditions of the sites the group visited. One big anomaly in both surveys was the prevalence of guards, which should deter looting. According to Lawrence Rothfield of the University of Chicago, three of the seven sites in the north (Hatra, Nimrud and Nineveh) "have been guarded since they were looted soon after the invasion of 2003." Similarly, three of the eight

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Breakthrough Leads to Windows That Produce Energy

CAMBRIDGE Mass.—University scientists have developed windows that collect solar energy. A major advancement, the windows use a special coating to absorb sunlight and then re-emit the energy into the glass, which conducts it to solar cells.

'Guerilla Gardeners' Take Initiative to Beautify Urban Areas

LOS ANGELES—People all over the world are reaching for rakes and shovels in an effort to transform neglected public spaces. And they're not waiting for permission from city officials. It's a grassroots movement that's growing. Literally. On any given Saturday night in cities from L.A. to London, you can find ordinary citizens pulling weeds alongside freeway off-ramps. Or planting flowers in vacant lots. And it's almost always done anonymously. In most cities, getting approval to beautify public property is nearly impossible. Not because anyone objects to the idea, but because bureaucracy often gets in the way. As a result, "guerilla gardeners" are quietly taking it upon themselves, donating time and resources to help change the face of their neighborhoods.

New Plastics Biodegrade in Just Four Months

ROLLA, Mo. — A team of researchers is creating new types of biodegradable plastic that will help reduce the amount of landfill-clogging waste Americans produce each year. The material, which modifies several bio-based, oil-based and natural polymers, could go a long way toward minimizing the size of landfills. Ultimately, the team hopes to develop a variety of applications for the plastic, including bags, bottles and product packaging.

Pact Protects 2,400 Square Miles of Amazon

GEORGETOWN, Guyana — With the support of a U.S.-based conservation organization, leaders from Guyana's Wai Wai tribe are working to protect their section of the rainforest from commercial loggers. The 2,400-square-mile Wai Wai-controlled section helps make up a vital area called the Guyana Shield, which includes approximately 25 percent of the tropical rainforests left in the world. It's also home to several rare animals, including the jaguar.

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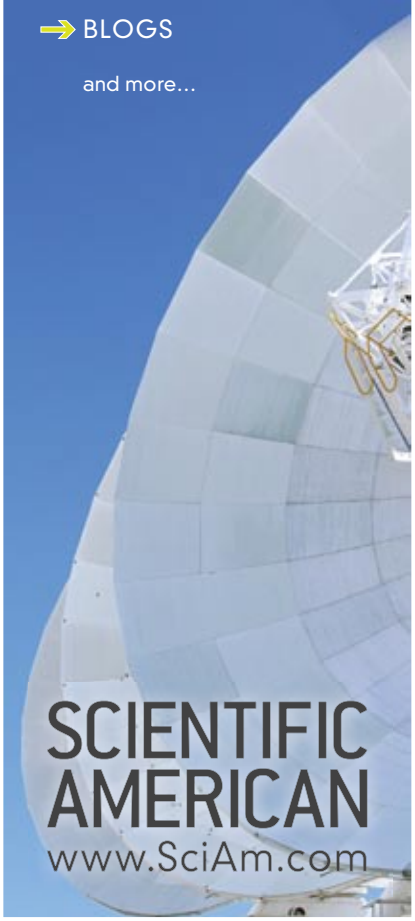
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sites surveyed in the south were guarded (Lagash, Ur and Uruk).

But guards at most archaeological sites in Iraq are a rarity. Elizabeth C. Stone of Stony Brook University, who was a member of the Iraqi-British project, tells how the survey team concluded that Larsa, another of the sites in the southern survey, was unguarded: "It was supposed to be visited occasionally, and it didn't look as though it was … because we found a hawk's nest with a rather cheerful baby hawk in it sitting on their watchtower." Part of the problem, Stone explains, is that although there is a mobile force of 1,500 Iraqi guards with trucks for patrolling the sites, "nobody has put any budget line in for fuel."

"There has been no comprehensive survey done to establish with certainty exactly what percentage of the 10,000 registered sites has been looted," Rothfield says. Military satellite imagery "would enable analysts to tell us the whole truth," he adds, but the military "has not been willing to share it."

Scholars and analysts must therefore base their estimates on satellite data from commercial sources, on eyewitness accounts and on what is being recovered by police and customs officials. Stone herself bought $150,000 worth of satellite images to look for the telltale signs of looting. With them she has documented looting holes equivalent to an area of 15.75 square kilometers—more than a quarter of the area of Manhattan. Most of the images she purchased, though, were made in 2003; more recent data are patchy—and expensive to come by.

The good news, she notes, is that a trade embargo and the threat of stiff legal sanctions seem to have dried up the market for looted artifacts—hence, perhaps, some of the incentive for looters. The sales of objects such as clay tablets and cylinder seals, Stone says, "just came to a screaming halt in 2003"—as the international community reacted to the sacking of the Iraqi National Museum in Baghdad with tough laws against buying and selling Iraqi antiquities.

Not all the damage to Iraq's ancient

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RECLAIMED BY THE DESERT? This past June, Iraqi and British inspectors visited the collapsed and looted ruins of this dig house at Tell Abu Shahrain (Eridu) in southern Iraq. Sumarian literature maintains that Eridu was one of the oldest cities in ancient Mesopotamia.

heritage is the fault of looters. At two sites (Tell al-Lahm and Ubaid), military command posts "had been established at the top of the site," according to the report of the Iraqi-British project. "Shelters for vehicles (tanks or armored personnel carriers) had been created" by cutting into the ancient mounds. The construction has presumably dug away "previously undisturbed archaeological deposits," the report added. At the site of Babylon, Stone remarks, military activities have removed areas of surface mounds totaling six hectares, or more than 13 football fields—to fill sandbags, carve trenches and bulldoze earth for parking lots.

In the view of art historian Zainab Bahrani, an Iraqi-born scholar at Columbia University, no serious assessment of the damage will be possible until the occupation ends. What has become clear to Bahrani, however, is that the looting of the Iraqi National Museum and of archaeological sites is only "the tip of the iceberg"—just part of a large-scale historical and cultural destruction of archives, libraries and universities, as well as members of the scholarly community. "So many people have died and become homeless and been forced into exile," she says, "that it becomes difficult for me to focus on cultural heritage alone."

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NEUROSCIENCE

Patches for Faces

Discrete brain sections form a dedicated network to recognize faces BY LIZZIE BUCHEN

As we walk along a city street, it takes no effort to recognize the face of a friend in the crowd. But the ease of the feat masks its cognitive complexity—all faces have eyes, noses and mouths in the same relative place and can bear an array of emotional expressions. For decades, scientists have debated the basis for our facility with faces: either human brains evolved specialized face-processing machinery, distinct from regions that deal with other objects, or they process all objects using an expansive, multipurpose network, merely developing an expertise for faces. Two experiments have now clarified this perennial dispute by uncovering a distinct network that is indeed dedicated to faces.

In the late 1990s brain-imaging studies revealed that discrete regions of the temporal lobe—a section of the human brain important for object recognition—fired up more strongly when people looked at faces than at any other thing. It was unclear, however, whether these regions actually contained cells that were specifically triggered by faces or whether they responded more broadly—activated by, for example, any object related to people or by something that required attention to detail.

A few years ago Doris Tsao and her then colleagues at Harvard Medical School addressed this matter. She located dedicated "face patches" in monkeys and discovered that these patches were packed with neurons that responded only to faces. "We demonstrated that they are highly specialized regions," says Tsao, now at the University of Bremen in Germany. "But we still didn't know how they worked—whether each patch was independent or whether they were all involved in a unified circuit."

So Tsao forged ahead, using a technically impressive combination of brain imaging and single-cell stimulation. She and her graduate student Sebastian Moeller used electrodes to prod neurons in specific face patches, while observing the rest of the brain with functional magnetic resonance imaging (fMRI). Earlier this year they reported finding that the face patches were tightly and specifically interconnected: stimulation of a face patch activated other face patches almost exclusively, whereas stimulation outside a face patch activated only nonface regions.



ABOUT FACE: **The human brain can easily pick out the familiar visage of a friend in a sea of other faces.**

"This really blew me away," says Margaret Livingstone, a neurobiologist at Harvard Medical School, who oversaw Tsao's earlier work. "The connectivity between different face patches is incredibly precise, face patch to face patch, suggesting that this is a really special system that's got its own anatomy, completely separate from all other objects."

Tsao then cast her eye on the frontal lobe, which turns sensory data into goal-directed behavior. "We don't just perceive faces—we respond to them," she explains. "We determine their emotional expression, store them in our memory, categorize them as friend or foe." So face patches could be in the frontal lobe, she thought.

Using fMRI, Tsao found three discrete face patches. One patch was in the orbitofrontal cortex, which evaluates emotions and social behaviors. Further testing revealed that emotional faces excited this patch more so than neutral faces, indicating that it might have a specific role in interpreting emotional expressions. (In contrast, the face patches in the temporal lobe did not respond any differently to emotional faces.) Indeed, injury to the frontal lobe can leave victims able to recognize people but unable to assess their mood.

Tsao now hopes to determine how each patch contributes to facial processing. She surmises that they may form a functional hierarchy—for example, one patch may detect faces, and then other patches chime in to report detection of, say, male faces or surprised faces. She strongly suspects these later patches may communicate with the medial temporal lobe, a region where, in 2005, Christof Koch of the California Institute of Technology discovered neurons that responded exclusively to specific individuals, such as actor Halle Berry. Tsao's findings hint at the step-by-step processing that results in neurons that can encode an entity as complex as a particular person.

"These areas are all connected," Koch remarks. "Not only can you see Halle Berry, but you can see if she's angry or if she's looking at you. This is a circuit that's dedicated to faces, and it goes all the way from the back of the brain to the very front." Such specialization for face processing is vital to our survival, Koch adds. "It doesn't matter if you're a baby, or an old person, or a nerd that stares at the floor. You are a social creature, and faces are important."

Lizzie Buchen is based in San Francisco.

GRAEME WILCOX

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The Evolution of the Genetic Code
Speaker: **Stephen J. Freeland, Ph.D.**

Why should all life use two utterly different chemical languages with which to construct itself? Why did it arrive at a single set of encoding rules for translating between them? How can the precise choice of coding rules influence life's struggle to stay one step ahead of extinction? You'll get the bottom line (as it stands now) on the origin and subsequent evolution of the genetic code from Dr. Freeland, including:

- the central dogma that unifies life
- the non-random "design" of genetic code words
- emergence from an RNA world
- the great unknowns

1859: The Impact of a Dangerous Idea
Speaker: **Jerry Coyne, Ph.D.**

In this session we'll trace the origin of Darwin's "dangerous idea" (actually several ideas) beginning with his famous voyage on the HMS Beagle. We will learn what Darwin really proposed, what impact the ideas of evolution and natural selection had on the Victorian world, and why Darwinism was — and still is — considered a dangerous idea.

Unconscious Design: Natural Selection
Speaker: **Jerry Coyne, Ph.D.**

While the idea of evolution was immediately accepted by 19th-century biologists, the concept of natural selection — the purposeless driving force of evolution and adaptation — has been much more controversial. This talk will describe what natural selection really is and see examples of how it works in nature. We will also examine the complementary theory of sexual selection, which explains the remarkable difference in appearance and behaviour between males and females in many species.

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On the Origin of Species, Really
Speaker: **Mohamed Noor, Ph.D.**

Although Darwin's book title suggested that he provided us with insights on the origin of species, in fact, he only focused on the process of divergence within species and assumed the same processes "eventually" led to something that could be called a new species. In this session, we'll talk about how species are identified (in practice and in principle), and then how modern evolutionary biologists use this type of information to get a handle on how species are formed.

From Magic to Muons: Why People Believe in Strange Things
Speaker: **Tania Lombrozo, Ph.D.**

Much of our knowledge is about things that we cannot see or touch. By studying human reasoning we can begin to understand both how people make scientific discoveries and how these processes can lead to some surprising errors in understanding our world. We'll consider the debate over evolution and intelligent design as a case study in people's understanding of and preference for different kinds of explanations for the world around us.

The Mathematics of Mind: Exploring the Formal Foundations of Human Thought
Speaker: **Thomas Griffiths, Ph.D.**

Over the last two millennia, scientists and philosophers have used approaches such as logic, artificial neural networks, and probability theory to develop scientific and mathematical models of thought. Dr. Griffiths will talk about current status of work to understand the formal principles that underlie human thought and our ability to solve the computational problems we face in everyday life.

Evolution of Individuality and Complexity Through Cooperation and Conflict
Speaker: **Richard Michod, Ph.D.**

Our understanding of life is being transformed by the realization that evolution occurs not only among individuals within populations, but also through the integration of groups of cooperating individuals into new higher-level individuals — that is, through evolutionary transitions in individuality (ETIs). The major landmarks in the diversification of life and the hierarchical organization of the living world are consequences of a series of ETIs: from genes to gene networks to the first cell; from prokaryotic to eukaryotic cells; from cells to multicellular organisms; from asexually reproducing individuals to sexually reproducing pairs; and from solitary individuals to societies. How do groups become new individuals? Cooperation and conflict play a major role in these evolutionary transitions. Join Dr. Michod and come away with a new perspective on the process of evolution and what it means to be an individual.

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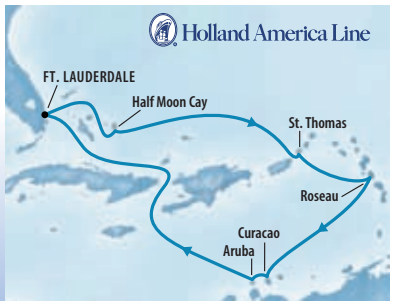


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Sampling of Topics

- Cognition • Complexity
- Darwin • Genetic Code
- Sex • Machine Learning
- Natural Selection • Speciation

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Sampling of Topics

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Sampling of Topics

- Space Shuttle Program
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PHYSICS

Blocking Sound with Holes

Anyone kept awake by a neighbor's television may be surprised to learn that a few holes drilled through a wall could lower the volume on sound. Francisco Meseguer of the Polytechnic University of Valencia in Spain and his colleagues placed a series of 20-centimeter-thick aluminum plates in a tank of water and found that perforated plates could diminish ultrasound waves passing through by up to another 10 decibels as compared with solid plates. This reduction was greatest when the spacing between the holes roughly equaled the sound's wavelength. Evidently, the incoming sound interacts with regularly spaced holes, generating acoustic waves on the plate's surface



QUIET, PLEASE: **Sound-canceling holes.**

that destructively interfere with waves going through the plate. The findings, in the August 22 *Physical Review Letters,* could help soundproof machines while allowing cooling air through, remarks Meseguer, who says his team is now experimenting with audible sound. —*Charles Q. Choi*

ENERGY

More Fluid Mileage

Electric fields can boost a car's gas mileage by up to 20 percent, thanks to a well-known effect in which electric fields reduce the viscosity of a liquid [see "Electrorheological Fluids"; Scientific American, October 1993]. Reduced fuel viscosity means that much smaller droplets can be injected into the engine, leading to more efficient combustion. Investigators at Temple University thinned fuel by attaching an electrically charged tube to a diesel engine's fuel line near the fuel injector. In road tests, the attachment, which consumed less than 0.1 watt, increased highway fuel economy from 32 to 38 miles per gallon. The researchers, who describe the boost in the November 19 *Energy & Fuels,* expect the device will find use in all kinds of internal-combustion engines. —*Charles Q. Choi*

BEHAVIOR

Sacrificial Ants

Every night the Brazilian ant *Forelius pusillus* takes selflessness to a whole new level. At dusk, as the ants defend their homes by sealing off the entrances with sand, up to eight workers remain outside to finish the job. Left behind, they die by the next day—the first known example of a suicidal mission that is preemptive rather than a response to immediate danger.

Behavioral ecologist Adam Tofilski of the Agricultural University of Kraków in Poland and his colleagues found that these ants were not just stragglers trapped outside. They were deliberately helping to cover the entrances, spending up to 50 minutes kicking sand into the holes until the entrances were indistinguishable from the surroundings. In experiments, the scientists found that only six of 23 ants left behind were alive the next morning, showing that their act was a sacrifice. Just why the ants died is unclear—the species is fragile, but the researchers also suspect that the outside individuals could be old or sick. The findings, in the November *American Naturalist,* could elucidate the evolution of altruism.

—*Charles Q. Choi*



THE 2008

NOBEL PRIZES

This month the king of Sweden will honor these 10 people of science for their achievements. Three of them—Luc Montagnier, Yoichiro Nambu and Paul Krugman—have written for *Scientific American.*

Physiology or Medicine: Harald zur Hausen of the German Cancer Research Center in Heidelberg, for his discovery that the human papillomavirus causes cervical cancer, and Françoise Barré-Sinoussi of the Pasteur Institute in Paris and Luc Montagnier of the World Foundation for AIDS Research and Prevention in Paris, for their discovery of the human immunodeficiency virus (HIV). In making its choice, the Nobel committee snubbed Robert C. Gallo of the University of Maryland, who proved that HIV causes AIDS.

Physics: Yoichiro Nambu of the University of Chicago, for the discovery of the mechanism of spontaneous broken symmetry, which helps to explain the masses of subatomic particles and the forces acting on them, and Makoto Kobayashi of the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan, and Toshihide Maskawa of Kyoto University, for the discovery of the origin of broken symmetry, which predicts the existence of at least three families of quarks.

Chemistry: Osamu Shimomura of the Marine Biological Laboratory in Woods Hole, Mass., Martin Chalfie of Columbia University and Roger Y. Tsien of the University of California, San Diego, for their discovery of the green fluorescent protein and its development as a visual tag in bioscience.

Economics: Paul Krugman of Princeton University, for his theories on international trade patterns and geography, which explain why cities are growing and why similar industries clump together.

FRANCISCO MESEGUER *Polytechnic University of Valencia (holes);* AP PHOTO (*Nobel medal*)

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In Brief

FREUDIAN VINDICATION

The actual benefits of intensive psychotherapy have long been controversial. Now investigators report that such therapy can be effective against chronic mental problems such as anxiety and depression. They looked at 23 studies involving 1,053 patients who received long-term psychodynamic therapy, which seeks clues into the unconscious roots of disorders and focuses on the relationship between patient and therapist. Psychotherapy that lasted a year or longer appeared significantly more beneficial for complex mental problems than shorter-term therapies and seemed cost-effective. Analyze more in the October 1 *Journal of the American Medical Association.* —*Charles Q. Choi*

THE DEADLY DOZEN

The Wildlife Conservation Society (WCS) has issued a report of 12 diseases that are likely to spread and get worse as the world warms up and precipitation patterns change, providing more opportunities for these outbreaks. They are bird flu (H5N1 influenza), babesiosis (a malarialike disease), cholera, Ebola, infections by animal parasites (such as the worm *Baylisascaris procyonis*), Lyme disease, plague, poisonings from algal blooms called red tides, Rift Valley fever, sleeping sickness, tuberculosis, and yellow fever. To prevent some of these ailments from becoming the next Black Death or 1918 flu pandemic, the WCS suggests monitoring wildlife to detect signs of these pathogens before a major outbreak erupts. —*David Biello*

SUCCESSFUL ROCK TRACKING

For the first time, investigators tracked a small asteroid (a few meters in size) before it hit the earth. A telescope that is part of the Catalina Sky Survey, based near Tucson, Ariz., is part of an effort to locate near-earth objects that could pose a collision hazard. It picked up the body, dubbed 2008 TC3, on October 6. Researchers then correctly predicted that the space rock would enter the atmosphere at 12.8 kilometers per second over northern Sudan at 5:46 A.M. local time the next day, releasing approximately one kiloton of energy. Objects of this size strike the earth once every few months. —*Philip Yam*

CONSERVATION

Vanishing Act for Mammals

A new survey of the world's 5,487 mammal species reveals that one in four is in danger of dying out—including some species of bats, the most numerous of mammals. The International Union for Conservation of Nature (IUCN) concludes that at least 1,139 mammals around the globe are threatened with extinction and that the populations of 52 percent of all mammal species are declining. South and Southeast Asia are home to the most threatened mammals. Deforestation and hunting are the prime causes of the rapid declines in land mammals, such as elephants in Asia; most endangered marine mammals, such as the vaquita porpoise in Mexico's Gulf of California, have succumbed to fishing nets, ship strikes or pollution.



PACHYDERM PREDICAMENT: Populations of Asian elephants are in steep decline.

Concerted efforts have brought some mammals, such as the black-footed ferret, back from the brink, but long-term success depends on tackling the root problems, the IUCN warns in its report published in the October 10 *Science*.

—*David Biello*

CHEMISTRY

Explosive-Free Mix

For the budget-conscious terrorist, fertilizer has been the ingredient of choice—because it contains ammonium nitrate, the chemical foundation of many kinds of bombs. Honeywell International—the Morristown, N.J.–based company famous for thermostats—has now patented a blast-free alternative. The company's fertilizer adds in ammonium sulfate, which binds to the ammonium nitrate and makes it unable to burn quickly. In tests, the fertilizer does not detonate even when mixed with diesel or other fuels. What remains to be seen is whether it performs well as plant food; target crops would be those that need both nitrate and sulfate, such as tomatoes, cabbages and potatoes. Honeywell plans to offer the product by the end of 2009. Farmers will likely pay more for the so-called Sulf-N 26 fertilizer, but those who use it will have some assurance that the Department of Homeland Security won't come calling when they buy in bulk. —*David Biello*



OKLAHOMA CITY BOMBING in 1995 was done by terrorists using conventional fertilizer, which contains ammonium nitrate.

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KONRAD WOTHE *Minden Pictures (elephant)*; DAVID LONGSTREATH *AP Photo (building)*

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In 1500, brave Portuguese navigators took their chances and went on a sea adventure to what would be one of the most fantastic adventures in history. Crossing an ocean filled with hope they arrived in Bahia, the crib of Brazil.

Five centuries later, the time of a new discovery. Powerful, the State of Bahia is now definitely in the circuit of global development, offering production of technology, universities, research centers, mild climate, skilled and versatile labor, abundant natural resources, more than 1,000 kilometers of coast, land for cultivation and the implementation of plant facilities, a great network of roads, railways, ports, airports and waterways – both ready and being expanded, built and in phase of planning – with respect for agreements signed, for benefiting the environment and social welfare.

Bahia is the natural link to the Brazilian Southwest – the most industrialized region of the country and its largest consumer center, where megalopoles such as São Paulo and Rio de Janeiro – are located, as well as the new centers located in the Northeast, North, West and mid-west of Brazil. Bahia has also a privileged location in the American continent, connecting South America to the Atlantic Ocean and the Northern Hemisphere. Going toward the west, we can find a network of roads and railways that connects Bahia to the Pacific. It is easy to say that from Bahia it is easy to get to the main markets of the planet.

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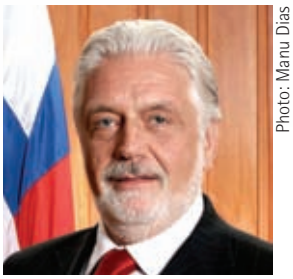


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Jaques Wagner
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GROWTH NUMBERS

Population
14 million – 66.5% in the urban area

Area
565,000 sq. km.

Coast
1,180 kilometers

Population of Salvador, the capital city
2.8 million

Bahia Gross National Product in 2008
US $49.9 billion – 4.3% of Brazilian GNP

Industry
US $22.3 billion generated in 2008; US $5.4 billion in protocols of intention signed between Jan. 2007 & Dec. 2008.

Exports
US $7.4 billion in 2007

Imports
US $5.4 billion in 2007

Bahia

HAVE A GREAT FUTURE HERE





In the last five years, Bahia's GNP has increased 27% according to the national trend. The low cost of raw materials and infrastructure aiming at the development of new business, plenty of skilled labor and its privileged location to logistics are some of the factors that have stimulated the growth.

With a territory larger than the whole of Spain (and the same size as France), Bahia has vast areas for plantations of oil plants for the production of biofuel without affecting food growth. There are four biomes – Mangrove, Atlantic Forest, Caatinga and Corral – with distinct characteristics for research and agro-business. Roads, ports, airports, hydroways and railways insure the mobility of goods and products.

Looking at the near future, new facilities are being implemented. This is the case of the West-East railway stretching 3,200 kilometers – 1,200 in Bahia's territory; it will connect a great port on the Atlantic Ocean to the Pacific, through Peru, interconnecting with other railways. The South Port, at the Atlantic end of the railway, is a modern integrated complex. In its more than 1,000 kilometers of coast, the longest sea coast in Brazil, Bahia also relies on the important ports of Salvador, Aratu and Ilhéus.

The energy matrix in Bahia is diversified. The State has excellent supplies of natural gas, guaranteed by local extraction, the Southeast-Northeast gas line and the great development of biomass. Besides castor oil, soybeans, cotton and sunflower, already strong in the State, Bahia has begun a new frontier of biofuels: Barbados nut. This new plant grows in arid soil, in regions of scant agriculture development, promising new horizons to researchers and entrepreneurs.

The mining sector is one that grows most, with the development of the steel industry. Nowadays, approximately thirty substances are explored, including oil, natural gas, uranium, copper, iron, gold and vanadium.

All of the State's industrial and technological development has, as a critical condition, social/environmental sustainability. There are clear rules as to the specific laws, and concerning haste in the licensing process. This is the assurance of biodiversity maintenance, joining natural wealth to the economic potential of undertakings.



Photos: SECTI/SICM



A VIGOROUS INDUSTRY

The largest petrochemical complex in the Southern Hemisphere, at Camaçari, is near the capital city of Salvador. The US has planned to invest US $4 billion by 2010. There are thirty-four companies in this sector operating with a capacity to produce 11.5 million tons a year, with high standards of environmental control.

Ford's modern plant is also located in Camaçari. Producing 250,000 cars a year, it houses one of five new product development centers the company has around the globe. Among the main areas of research is replacement of conventional plastic by a polymer based on sisal, a vegetal fiber typical of semi-arid climates. The material is lighter and more resistant than the one currently used and has a lesser environmental impact when disposed.

The Northeast Ford Industrial Complex was planned to meet the highest standards of environmental conservation. All residues and effluents are treated and reused, in a self-sustainable system. The sewage and the water produced by the plant are forwarded to the wetlands, ecologic stations with rice and bulrush plantations, filtering the wastes, returning the pure water to the soil, reused in the Complex.

Bahia has sixteen industrial centers in operation spread throughout the whole territory. The government guarantees various fiscal and financial incentives to new companies with innovative potential. In addition, infrastructure for a science park is approaching conclusion.

COMPARATIVE ADVANTAGES

The largest petrochemical pole of the Southern Hemisphere
The third largest oil refinery of Brazil
The largest automotive manufacturing complex of the Northeast of Brazil
25% of the national production of computers in the country
40% of the natural gas production in the Northeast of Brazil
30% of the national export of fruits
Biggest bovine and goat producer in the Northeast of Brazil

Bahia

EDUCATION AND QUALIFICATION: BAHIA PRIORITIES

The creativity of Bahia's people, evidenced in their music and cultural expressions such as *Capoeira*, also results in inventions and innovations. The Brazilian government considers investment in research and technology strategic and, therefore, increased from 1.05% to 1.5% (of the Gross Internal Product) governmental resources for the sector over the next three years. In the same sense, the Innovation State Law establishes a new paradigm for the scientific and technological development of Bahia. The new view is that science and technology should inform all government actions from health to urban development, including agriculture, industry and education.

In Bahia, the productive sector, universities, research centers and government all work in an coordinated manner to optimize efforts and bring better results. The Research Support Foundation (Fundação de Amparo à Pesquisa), for example, offers resources through several lines of incentive, especially through open competition for researchers. The amount available should exceed US $29.5 million this year, triple what was available six years ago. All that without increasing spending by the federal government. The State also works with a program for the attraction and hiring of PhD-holders and devotes special attention to studies of semi-arid climates – a not very much explored biome with a lot of potential, especially for biotechnology.



Photo: FIEB

Senai CIMATEC: Supporting automotive and manufacturing in Bahia



Year	Enrollment in universities*
2002	5,331
2003	4,566
2004	67,041
2005	71,646
2006	73,296

*Including UFBA
Source: INEP

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Fiocruz Bahia is a leading institution in research, technological development and human resources training for life sciences

INVESTMENTS

Bahia has strongly invested in qualifying workers and researchers. Between 2002 and 2006, the total of PhD-holders working in Bahia more than doubled and incentive programs attracted new researchers. The number of students enrolling in the universities is increasing, 32% more comparing with the same period. Today, more than 70,000 young *baianos* (people form Bahia) enroll in universities each year.

There has been an increase of graduates, master's and doctoral courses in the last decade, ensuring skilled labor to current and new undertakings. The qualified labor offer in the Northeast exceeds the current demand. There are 135,000 people holding a higher degree, seeking a job and, with the new graduates, the number of good workers will be even larger.

In the long-term, dozens of centers of technological studies are being implemented to complement the basic education in strategic sectors, such as information technology and biochemistry. An ample program for IT education is preparing 20,000 students to work in several areas of computer sciences and otherstimulating technological careers.

One of them, being currently implemented in the city of Serrinha, in the Semi-Arid, is coordinated by Professor Dr. Miguel Nicolelis, head of the neuroscience lab at Duke University, USA. Those are the *baianos*, scientists-to-be, who start their preparation from an early age to work in robotics, information technology, chemistry and physics.

PROFESSIONAL EDUCATION
R $140 million will be invested in Bahia by 2011.

Implementation of 140 school units and expansion to 70,000 students registered.

Priority areas: Biotechnology, Information Technology (IT), Industrial Control and Process, Mineral Product, Agriculture and Cattle raising activities and Water (Maritime and Fluvial), Mining, Biofuel and Agr business.

UFBA Universidade Nova

A NEW PARADIGM IN RESEARCH AND HIGHER EDUCATION IN BRAZIL

This fast-growing Brazilian university is renewed with excellence in teaching and research, and expansion of the international exchange program for students, teachers and researchers.

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President Naomar Almeida-Filho, building a new university in Bahia



The Universidade Federal da Bahia (UFBA), founded in 1808, is the oldest higher education institution in Brazil. It is composed of two modern, eco-sustainable campuses in Salvador, the first capital city of Brazil, home of *samba, capoeira, candomblé* and other features of the powerful cultural heritage brought by African slaves in colonial times. The university has 2,000 faculty and 26,000 students in 101 professional degree courses, 87 master's and 35 doctoral programs.

UFBA welcomes international partnerships with enterprises and technological institutions to strengthen its capacity to train researchers and developers in dynamic fields of science and technology. In the past 6 years, UFBA has signed agreements with more than 180 academic and research institutions from around the world. Currently, more than 300 UFBA students are abroad, while more than 200 foreign students are attending professional and post-graduate courses in Bahia. Special programs such as the Collége Doctorale with France, international joint PhD courses with Canada and the US, academic cooperation with Argentinean and African universities and the Summer University of Bahia have been planned with fine prospects for a future of increasing internationalization of the institution.

UFBA is regarded as one of the leading knowledge centers in Brazil, well-known for developing the most diversified repertoire of research areas: from Architecture and Urban Planning to Nanotechnology and Computation of Distributed Systems, from Communication and Management to Law studies, from the Arts (its graduate programs of Performing Arts and Musicology are ranked top in the country) to Health Sciences (leading research groups are on Epidemiology, Health Planning, Immunology and Clinical Medicine). Recently, UFBA has implemented a series of innovative interdisciplinary post-graduate programs and research centers in several fields, such as Energy & Environment, Gender Studies, Culture & Society, Ethnic and Afro-Brazilian Studies, Information Technology, History & Philosophy of Science. Also, through the Bahia Institute of Technology, UFBA has been associated with Petrobras (the leading oil company of Brazil) to develop new technologies for biofuel and oil prospection and with FIOCRUZ (the leading research center in the health sector) for biotechnology that can be applied to large-scale health problems.

Thanks to a university restructuring program funded by the federal government under President Lula, UFBA has become the fastest-growing institution of its kind in Brazil. From 2002 to 2008, there has been an increase of 69% in openings for undergraduates, 113% for master's and 213% for PhD programs. The university's 2008-2012 master plan projects a massive growth of 17,000 professional and 5,000 post-graduate students.

But the change is not only in size. Overcoming 200 years of tradition and after a radical renewal, UFBA is now the first university in Latin America to offer a degree system compatible with the US college+master's/PhD and the European Bologna Process. The new UFBA curriculum (known as Universidade Nova) is based on Interdisciplinary bachelor's degrees, designed for providing a high-quality humanistic, cultural and scientific background for professional and academic master's and doctoral programs.

To accomplish growth with academic quality, UFBA is planning to hire more than 1,000 teaching personnel in the next three years in the following areas of interest: Energy Research, Nanotechnology, Communication & Information Technology, Earth Sciences, Life Sciences, Environment & Sustainability, Biotechnology, Oil Industry, Engineering, Chemistry, Performing Arts, Audiovisual Studies, Psychology, Social Work, Humanities, Law Studies, Business Administration, Public Health, Nutrition and other fields. Brazilian or Latin American researchers and postdoctoral fellows who are working abroad and want to return home are most welcome at UFBA; but the recruiting committee will also consider other experienced teachers and researchers interested in contributing to the development of the Universidade Nova in Brazil.



Photos: Célia Aguiar

POST-GRADUATE COURSES
Changes in the Number of Vacancies

Course	2002	2003	2004	2005	2006	2007	2008	2009	%Growth
Master's	59[illegible]	[illegible]13	845	859	976	940	970	1,097	8[illegible].9
PhD	159	256	238	231	290	383	435	498	213.2
[illegible]otal	749	1,069	1,083	1,100	1,266	1,323	1,405	1,595	113.0

POST-GRADUATE PROGRAMS (AREA OF RESEARCH)

Great Area	Number of Courses
Health Sciences	14
Human Sciences	12
Social Sciences	12
Natural Sciences	10
Engineering	9
Arts and Humanities	8
Biological Sciences	7
Agricultural Sciences	3
Multidisciplinary	12
Total	87

Bahia Science Park

Bahia Science Park

www.tecnoviaparque.com.br

CENTRAL CONCEPT

The Technological Park is where the public, private and academic sectors converge for innovation in the Bahia State. Its central goals are to attract innovative companies, stimulate cooperative research projects with industry and to strengthen the technological entrepreneurship in the State. The Park has been organized based along three axes: Innovation Way (as a tool to attract enterpreneurs), Technological Way (as the institutional center of support for the interaction between universities and companies) and Science Way (as a strategy to strenghthen the local critical mass and to continue the improvement and generation of knowledge).

INVESTMENTS FOR NEW ENTREPRENEURSHIPS

Combining the three axes above, the State of Bahia is dedicated to creating an environment that financially stimulates innovation. Several specific incentives were created and are being expanded to stimulate innovation and to attract innovative enterprises. Among those is the creation of a fund that grants US $50 million over the next four years in nonreimbursable resources to the development of infrastructure and acquisition of equipment for innovative projects, to reductions of tax rates for companies in the service sector and to the growth of available financing for research through public notices for funding supporting innovation.

At the federal level, the National Bank of Development (BNDES) has US $40 billion per year for industrial investments and innovation support. The Ministry of Science and Techonology is injecting US $1.5 billion in 2009 and forecasting growth of this amount in the next years. Of this total, US $250 million are exclusively designated for innovation in the private sector.

PROJECT DETAILS

The Park meets the highest urban standards, covering a potential area of one million square meters, located in an area that is the vector of growth of the capital city. Projected to accommodate companies dedicated to world-class knowledge in the areas of Biotechnology, Engineering, Power and the Environment, and Information Technology and Communications, careful consideration of the environment permeates the project. The architectural concept of the Technological Park reflects its primary goal of promoting sustainable development, as it integrates technologically sophisticated structures with preservation of the native Atlantic forest, one of the richest Brazilian biomes.

To be concluded in December 2009, the first phase of the project places side-by-side public and private lands, with areas of 150,000 and 430,000 square meters, respectively. The main office is located only four kilometers from Salvador International Airport, less than five minutes from the State Government Administrative Center and near some of the main universities and centers of local research. The place ensures its future residents the possibility of collaboration in an area of close proximities, as well as fast and comfortable access to the scientific and public facilities of the State with minimum effort.





AASDAP

SCIENCE AS AN AGENT OF SOCIAL TRANSFORMATION

AASDAP
ASSOCIAÇÃO ALBERTO SANTOS DUMONT PARA APOIO À PESQUISA

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www.natalneuro.org.br

Since it was established on April 17, 2004, the Alberto Santos Dumont Association for the Advance of Science (AASDAP), a Brazilian non-profit, non-government organization, has promoted the philosophy that top-level scientific enterprises can decisively contribute to the social and economic development of underprivileged communities in the poorest regions of Brazil. Founded by a group of Brazilian scientists and citizens interested in promoting the concept that science plays a key role in the development of modern and democratic societies, AASDAP has proposed a comprehensive plan to establish a network of "Science Cities" throughout the North and Northeast regions of Brazil as a way to promote the production and dissemination of innovation and knowledge throughout the country.



To achieve this central mission, over the last four years, AASDAP has implemented the first phase of its "Campus of the Brain" project in the cities of Natal and Macaíba, Rio Grande do Norte state, in the northeast of Brazil. Such an ambitious initiative, which aims at linking state-of-the-art neuroscience research both to new models for providing health care for women and children and to best practices for educating children, will serve as a new paradigm for other AASDAP initiatives in Brazil and abroad. Currently, the "Campus of the Brain" houses the Edmond and Lily Safra International Institute of Neuroscience of Natal, a state-of-the-art brain research institute. The campus also includes the Alfredo J. Monteverde School, where 1,000 children from one of the poorest public school districts in the country participate in a comprehensive, after-school science education program and where they have access to state-of-the-art biology, chemistry, physics, robotics, and computational laboratories. The campus also houses the Anita Garibaldi Health Clinic, where women and children from the surrounding community receive high quality and free primary health care.

Thanks to a grant awarded by the Brazilian Ministry of Education, the second phase of construction of the "Campus of the Brain" is under way. This will include a regular public school with capacity for 5,000 students, serving children from infancy through the completion of high school, and a 10,000 sq. m. Brain Research Institute. Future plans include the creation of a Biotechnology Research Park and the "City of the Brain" district next to the campus.



Following the success of this first initiative, AASDAP has signed a broad agreement with the state government of Bahia to establish its second institute in the semi-arid region of that state, the largest in the Brazilian Northeast. Thus, plans are under way to launch the International Institute of Biotechnology and Bioprospection of the Bahia Semi-arid in 2009–2010. In addition to several lines of biotechnology research, including plant genetics and selection of new oil seeds for biodiesel production, the institute will launch a renewable energy initiative and a science education program for 400 children living in the semi-arid city of Serrinha.



Photos: AASDAP, Cristóbal Corral Vega





Finally, in collaboration with the largest Brazilian Hospital, the Sírio-Lebanese Hospital, located in São Paulo, AASDAP has established modern clinical neurophysiology laboratories to carry out state-of-the-art projects, managed by international research consortia. These consortia link leading brain research institutes from all over the world together to find new therapies for neurological diseases that affect millions of people worldwide.

This is AASDAP's way of telling the world that Brazilians are creating new methods for the advancement of science.

Sebrae

BRAZILIAN MICRO AND SMALL BUSINESS SUPPORT SERVICE

Brazilian Micro and Small Business Support Service

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SEBRAE, the Brazilian Micro and Small Business Support Service, is a non-profit private institution whose mission is to promote the competitiveness and sustainable development of micro and small businesses in Brazil and to encourage entrepreneurship.

Today, SEBRAE has offices in all 26 Brazilian states and the Federal District, forming a wide network with approximately 800 points of service.

In the State of Bahia, SEBRAE supports micro and small companies from industry, trade, services and agri-business segments through both its collective projects and its individualized services available at its 31 locations in the state.

Within its organizational structure, five knowledge and technology sectors are present and, among them, the Access to Innovation and Technology Unit whose objective is to offer technology and innovation solutions in areas of management, marketing, process and production to micro and small businesses in Bahia.



Photo: Welton Araujo

ACCESS TO INNOVATION AND TECHNOLOGY UNIT

As industry changes with growing demands for higher quality, sophistication and customization, companies are forced to become more competitive and to differentiate their products and services. It is in this context that SEBRAE's support and expertise come in: to offer solutions toward increasing the ability of small businesses to compete and sustain themselves.



Photo: Arquivo SEBRAE

In the State of Bahia, SEBRAE – always in partnership with science and technology institutions – has been taking action to promote innovation and technology in order to significantly increase the solutions offered to small business.

Within these solutions we find courses and consultancy in process and product improvement, design (visual identity, packing), efficient energy use, waste reduction, hygiene and food handling, good manufacturing practices, labor health and safety, metrology, process and product certification, normalization and intellectual property rights (trademarks and geographical indications). SEBRAE also promotes fairs, exhibitions and technology trade shows; supports innovation and technology networks; bids to promote innovation and access to technology, agreements, partnerships and covenants with science and technology institutions; educational materials; holds innovation and technology awards and contests.

Besides this support to micro and small businesses through innovative efforts in management, marketing, process and product, SEBRAE also assists social technology transfer such as the Sustainable and Integrated Agro Ecological Program (PAIS). This program's objectives are to improve the quality of life and to promote social inclusion and sustainability by stimulating organic agriculture through pesticide-free processes. An investment of US $2,400 per property results, on average, in a return of US $600 per month. This return, which is extremely significant to the communities, happens, approximately, in 90 days.

Banco do Nordeste

THE NORTHEAST: BRAZIL'S CHINA

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www.bnb.gov.br

In times of turbulence for the world's economy and vanishing global credit opportunities, Brazil's Northeast region, as it is known, is a good alternative for those who wish to invest in the industrial sector. With an economy in constant expansion, this region, which was mostly known for its natural beauty, has since improved its electric power and transportation infrastructure and can now reveal its full potential.

Advantages such as its proximity to the North American and European markets, stable climate and qualified professionals, have drawn a great deal of attention from investors that regard the Northeast region as an auspicious site in which to stage an increasingly wide variety of businesses, especially those centered on tourism and agribusiness. The consumer market of the Northeast region has been growing year after year. According to a recent census conducted by Brazil's Statistics and Geography Institute (IBGE), in 2005 and 2006 the average family income in the region grew beyond national averages, reaching a 12% increase during that period.



Luiz Henrique Mascarenhas

The Gross Domestic Product (GDP) also has been increasing steadily above national averages. From 2002 to 2006 it is estimated that the accumulated economic growth was approximately 25% while Brazil's figures remain around 16%. The state of Bahia possesses the highest GDP index in the region and is also a leader when it comes to generating registered job opportunities. Only last year, 56,000 new job opportunities were created in the state.



Resort Hotel

Another differentiating factor that distinguishes the Northeast region from others in Brazil is the availability of low-interest financing opportunities with excellent rates. In this aspect, Brazil's Northeast Bank (BNB), an institution that has been steadily leveraging the region's economy now for fifty-six years, deserves a chapter by itself. Considered the largest regional development bank in Latin America, BNB has the Constitutional Northeast Financing Fund (FNE) as its main funding source, created by the Federal Government in 1989 with a goal to widen credit opportunities and secure the Northeast region's place in the dynamics of national economy.



Business Hotel

In the last nineteen years, BNB has already applied some R$46.8 billion, at constant rates from June 2008 derived from the FNE in the Northeast, to finance activities in all sectors of economy. Almost half of this amount was contracted between 2003 and 2008, a fact that demonstrates this region's unrestrained business expansion trend. The bank's finances and currency exchange director, Mr. Luiz Henrique Mascarenhas, highlights the fact that aside from financing with the best rates in the country, the institution also offers its investors the required technical support. "One of our greatest assets is business information. BNB has an extremely qualified project analysis staff. We also count on our own research office called Etene (Technical Office for Economic Studies of the Northeast Region) that conducts global and sector-oriented studies that have been affording guidelines for our actions and that have been revealing investment opportunities. All this knowledge base is available to our clients", he says. BNB has credit lines focused on segments such as agriculture, technology, industry, commerce and tourism services. Interest rates for programs that employ FNE resources vary between 5% and 10% a year, according to the company's size and location. Terms for paying off debts can reach twelve years, with up to a four-year grace period depending on the proposed activity. The bank also offers a 25% default-on-payment bonus over interest, in case the enterprise is located in the semi-arid region and 15% if located in other regions.

A POTENTIAL FOR TOURISM

Tourism is one of the most promising activities in the Northeast. The favorable winds that have been driving the region's economy have brought more qualified tourists in increasing numbers. Impresario Mr. Marcelo Fonseca, executive director of the Deil Empreendimentos group that operates in the hotel segment in Salvador, is one of Northeast Bank's clients who is exploiting this market niche. Recently, his group inaugurated its Catussaba Business Hotel in that capital city, an enterprise of some R$15 million. Of this total, R$6.5 million came from resources derived from FNE.

The hotel targets the business tourist operating in neighboring localities including business executives from the Petrochemical Center, from the Ford Automotive complex, from Aratu's Industrial center and surrounding industries as well. "With the opening of Business Hotel, the Deil group takes another step towards consolidating its path in Salvador's hotel industry, with BNB supporting the enterprise's implementation. The group will offer quality services both for the tourist as for the business traveler", points out the bank's state superintendent in Bahia, Mr. Nilo Meira Filho.

The enterprise is responsible for generating 130 direct jobs and some 400 indirect job opportunities. The hotel offers 133 apartments over a 6,500 sq. m., a business center and an events hall for 120 guests. It also offers computers, medical assistance, a pharmacy and several leisure options that can also interest the casual tourist such as a restaurant, a sports court, swimming pool, a deck and bar, a mini shopping center and a beauty parlor among others. "It is certainly an advantage to count on BNB's support that makes the whole enterprise feasible, affording us a low financial cost if compared to other banks and that also offers an adequate payment term", states Fonseca. Through the Cresce Nordeste (Northeast Growth) Tourism Program, that makes use of FNE resources, the bank finances construction, improvements and installations, transportation vehicles in connection with the enterprise, training and technical and business assistance. Investments in infrastructure such as sanitation construction work, transportation and urbanization count on the forefront Northeast Tourism Development Program (Prodetur/NE) that has resources from the Inter-American Development Bank (IDB). BNB has 177 agencies spread out in the Northeast region and in the north of the states of Minas Gerais and Espírito Santo and is present in 1,989 towns in Brazil.



Catussaba Business

Cetrel

AN ENVIRONMENTAL PROTECTION COMPANY

cetrel
Proteção Ambiental

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Cetrel began operations in 1978, along with many other companies in the Camaçarí Industrial Complex, the largest integrated industrial park in Latin America. Cetrel is responsible for the treatment and disposal of wastewater and industrial wastes generated by the complex facilities as well as monitoring the environment inside the complex and in the surrounding areas.

Cetrel emerged as the first Brazilian privately-owned company specifically created to facilitate the integrated environmental protection for this large industrial complex. At that time, this concept was truly innovative. Environmental matters were not among the main concerns when industrial enterprises were installed.

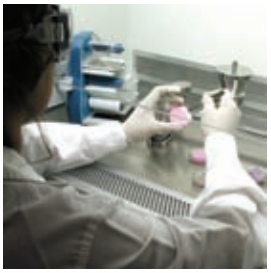
Created initially to treat the wastewater and dispose of industrial wastes, Cetrel gradually increased the scope of its activities and today is active in all fields of environmental engineering. Cetrel treats the wastewater, processes the solid wastes in special industrial landfills, incinerates liquid wastes and dangerous solid wastes as well as carries out the environmental monitoring of the air, the underground and superficial waters and the fauna in the surrounding areas affected by the activities of the Camaçarí Industrial Complex. Cetrel has also developed initiatives to encourage social responsibility through its Programs of Environmental Education and the Study and Preservation of Fauna. Always seeking continually to improve its company and operational performance, Cetrel is a pioneer in Brazil in the adaptation of the concept of sustainable development.



The Waste Water Treatment Plant of Cetrel









INNOVATION

Despite the advanced technology of its environmental protection systems, Cetrel also recognizes the need to push the bounds of innovation in order to meet the growing needs of industry. Combining ecological industrial practices with sustainability principles and a culture of innovation, the company is invested in emblematic strategies to transform ideas into new business opportunities that would help both solve and prevent environmental impacts in the complex.

For Cetrel, to innovate is vital. After all, market necessities change so quickly that current services and technologies are out of date in a very short time. The environment keeps changing and demands new solutions for business, products and services.

Understanding this new reality, Cetrel created a vigorous Innovation Program called PIC, which is proving to be one of the principal tools as the company constructs its future. Launched in March of this year, the program will be a major strategic challenge for Cetrel in the coming years, as it seeks to inculcate a "Culture of Innovation" in all its productive processes, in order to position Cetrel as a resource for market solutions in environmental protection.

Already, Cetrel has many projects being developed by a specialized team of people with the same goal – to generate innovative ideas that give a competitive advantage to the company. Some relevant projects are as follows: a) sulphur recovery from solid wastes, wastewater and gaseous emissions using integrated technological routes in order to provide sulphur as raw material for industry; b) development of a membrane system for removing SO2 and NOx from gaseous emissions using nanocomposites of ceramic and polymeric matrix; c) development of nanocomposites reinforced with natural fibers (such as sugar cane) or glass fibers and particulate matter (such as solid inorganic wastes) to produce new materials with low cost and improved properties; d) improvement of road pavement properties using rubber tire and scraps wastes reforced with industrial solid wastes (particulate matter).

In this way, innovation has become a strategic cornerstone for the activities of the firm and serves to invent creative approaches that yield positive results for Cetrel, its clients and the society at large.



Prototypes of different products made with sugar cane bagasse and incinerator ash from Cetrel.

SciAm Perspectives

After the Crash

Overreliance on financial software crafted by physics and math Ph.D.s helped to precipitate the Wall Street collapse

BY THE EDITORS



MATT COLLINS

If Hollywood makes a movie about the worst financial crisis since the Great Depression, a basement room in a government building in Washington will serve as the setting for a key scene. There investment bankers from the largest institutions pleaded successfully with Securities and Exchange Commission (SEC) officials during a short meeting in 2004 to lift a rule specifying debt limits and capital reserves needed for a rainy day. This decision, a real event described in the *New York Times,* freed billions to invest in complex mortgage-backed securities and derivatives that helped to bring about the financial meltdown in September.

In the script, the next scene will be the one in which number-savvy specialists that Wall Street has come to know as quants consult with their superiors about implementing the regulatory change. These lapsed physicists and mathematical virtuosos were the ones who both invented these oblique securities and created software models that supposedly measured the risk a firm would incur by holding them in its portfolio. Without the formal requirement to maintain debt ceilings and capital reserves, the commission had freed these firms to police themselves using risk tools crafted by cadres of quants.

The software models in question estimate the level of financial risk of a portfolio for a set period at a certain confidence level. As Benoit Mandelbrot, the fractal pioneer who is a longtime critic of mainstream financial theory, wrote in *Scientific American* in 1999, established modeling techniques presume falsely that radically large market shifts are unlikely and that all price changes are statistically independent; today's fluctuations have nothing to do with tomorrow's—and one bank's portfolio is unrelated to the next's. Here is where reality and rocket science diverge. Try Googling "financial meltdown," "contagion" and "2008," a search that reveals just how wrongheaded these assumptions were.

This modern-day tragedy could be framed not only as a major motion picture but also as a train wreck or plane crash. In aviation, controlled flight into terrain describes the actions of a pilot who, through inattention or incompetence, directs a well-functioning airplane into the side of a mountain. Wall Street's version stems from the SEC's decision to allow overreliance on risk software in the middle of a historic housing bubble. The heady environment permitted traders to enter overoptimistic assumptions and faulty data into their models, jiggering the software to avoid setting off alarm bells.

The causes of this fiasco are multifold—the Federal Reserve's easy-money policy played a big role—but the rocket scientists and geeks also bear their share of the blame. After the crash, the quants and traders they serve need to accept the necessity for a total makeover. The government bailout has already left the U.S. Treasury and Federal Reserve with extraordinary powers. The regulators must ensure that the many lessons of this debacle are not forgotten by the institutions that trade these securities. One important take-home message: capital safety nets (now restored) should never be slashed again, even if a crisis is not looming.

For its part, the quant community needs to undertake a search for better models—perhaps seeking help from behavioral economics, which studies irrationality of investors' decision making, and from virtual market tools that use "intelligent agents" to mimic more faithfully the ups and downs of the activities of buyers and sellers. These number wizards and their superiors need to study lessons that were never learned during previous market smashups involving intricate financial engineering: risk management models should serve only as aids not substitutes for the critical human factor. Like an airplane, financial models can never be allowed to fly solo.

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Sustainable Developments

Priorities for Fixing the Financial Crisis

Policies can avert disaster only if they interrupt the cascading threats to the U.S. economy

BY JEFFREY D. SACHS



The origin of the U.S. financial crisis is that commercial and investment banks lent trillions of dollars for housing purchases and consumer loans to borrowers ill equipped to repay. The easy lending pushed up housing prices, which then ratcheted still higher when speculators bought houses on the expectation of yet further price increases. When the easy lending slowed and then stopped during 2006 and 2007, the housing prices peaked and began to fall. The housing boom began to unravel and now threatens an economy-wide bust.

The U.S. economy faces four cascading threats. First, the sharp decline in consumer spending on houses, automobiles and other durables, following the sharp decline in lending to households, will cause a recession as construction of new houses and production of consumer durables nose-dive. Second, many homeowners will default on their mortgage payments and consumer loans, especially as house values fall below the mortgage values. Third, the banking sector will cut back severely on its overall lending in line with the fall in its capital following the write-off of bad mortgage and consumer loans. Fourth, the retrenchment of lending now threatens even the shortest-term loans, which banks and other institutions lend to one another for working capital.

The gravest risks to the economy come *back to front*. The fourth threat is by far the worst. If the short-term commercial paper and money markets were to break down, the economy could go into a severe collapse because solvent and profitable businesses would be unable to attract working capital. Unemployment, now at 6 percent, could soar to more than 10 percent. That kind of liquidity collapse was why national incomes in some Asian economies fell by around 10 percent between 1997 and 1998 and was why the U.S. economy fell by around 30 percent in the Great Depression.

The third threat, the serious impairment of bank capital as banks write off their bad loans, could cause a severe recession but not a depression. Unemployment might rise, for example, up to 10 percent. The ongoing fall in bank capital is already forcing banks to cut back their outstanding loans. Major investment projects are being scaled back. Some major nonfinancial companies will likely go bankrupt as well.

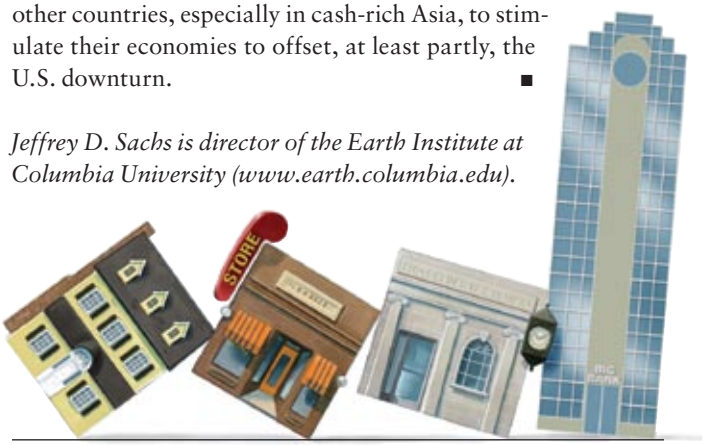
The second threat, the financial distress of homeowners, will be painful for millions of households. Many will lose their homes; some will be pushed into bankruptcy. Others may see their credit terms eased in renegotiations with their banks. Consumers as a group will start to become net savers again after years of heavy net borrowing. That trend will not be bad in the long term but will be painful in the short run.

The first threat, the cutback in sales of housing and other consumer durables, is the Humpty Dumpty of the economy that cannot be put back together. The inventory of unsold homes is now large; housing demand and new construction will be low for many years. Consumer spending on appliances and cars is also plummeting. These consequences are largely unavoidable and will force the U.S. into at least a modest recession, with unemployment likely to rise temporarily to perhaps 8 percent.

The goal of any new policy must be to avoid an outright collapse or deep recession. Two actions are thus critical. Most important, the government and the Federal Reserve must prevent the collapse of working capital by supplying short-term loans and taking other measures to sustain the commercial paper market, interbank lending and the smooth functioning of money market funds. The government should also aggressively promote a recapitalization of the banking system, with both public and private funds, so that bank lending is not squeezed for years to come. Unfortunately, the $700-billion bailout approved by Congress does not focus adequately on those liquidity or recapitalization challenges.

The legislation is better than nothing (to help forestall panic), but the real work of stabilizing and recapitalizing the banking system will now await the next administration, and the Federal Reserve Board will need to stay aggressive to prevent a liquidity collapse. Additionally, the government should encourage easier repayment terms on existing mortgages and engage with other countries, especially in cash-rich Asia, to stimulate their economies to offset, at least partly, the U.S. downturn. ■

Jeffrey D. Sachs is director of the Earth Institute at Columbia University (www.earth.columbia.edu).



PHOTOGRAPH BY BRUCE GILBERT/EARTH INSTITUTE; ILLUSTRATION BY MATT COLLINS

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Skeptic

Patternicity

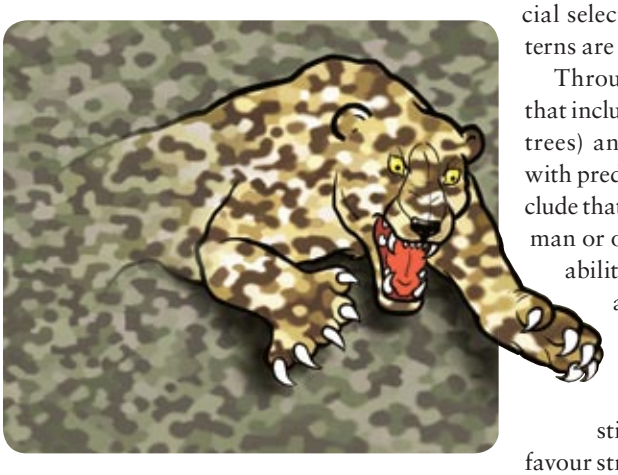
Noun. The tendency to find meaningful patterns in meaningless noise

BY MICHAEL SHERMER



Why do people see faces in nature, interpret window stains as human figures, hear voices in random sounds generated by electronic devices or find conspiracies in the daily news? A proximate cause is the priming effect, in which our brain and senses are prepared to interpret stimuli according to an expected model. UFOlogists see a face on Mars. Religionists see the Virgin Mary on the side of a building. Paranormalists hear dead people speaking to them through a radio receiver. Conspiracy theorists think 9/11 was an inside job by the Bush administration. Is there a deeper ultimate cause for why people believe such weird things? There is. I call it "patternicity," or the tendency to find meaningful patterns in meaningless noise.

Traditionally, scientists have treated patternicity as an error in cognition. A type I error, or a false positive, is believing something is real when it is not (finding a nonexistent pattern). A type II error, or a false negative, is not believing something is real when it is (not recognizing a real pattern—call it "apatternicity"). In my 2000 book *How We Believe* (Times Books), I argue that our brains are belief engines: evolved pattern-recognition machines that connect the dots and create meaning out of the patterns that we think we see in nature. Sometimes A really is connected to B; sometimes it is not. When it is, we have learned something valuable about the environment from which we can make predictions that aid in survival and reproduction. We are the ancestors of those most successful at finding patterns. This process is called association learning, and it is fundamental to all animal behavior, from the humble worm *C. elegans* to *H. sapiens*.



Unfortunately, we did not evolve a Baloney Detection Network in the brain to distinguish between true and false patterns. We have no error-detection governor to modulate the pattern-recognition engine. (Thus the need for science with its self-correcting mechanisms of replication and peer review.) But such erroneous cognition is not likely to remove us from the gene pool and would therefore not have been selected against by evolution.

In a September paper in the *Proceedings of the Royal Society B*, "The Evolution of Superstitious and Superstition-like Behaviour," Harvard University biologist Kevin R. Foster and University of Helsinki biologist Hanna Kokko test my theory through evolutionary modeling and demonstrate that whenever the cost of believing a false pattern is real is less than the cost of not believing a real pattern, natural selection will favor patternicity. They begin with the formula $pb > c$, where a belief may be held when the cost (c) of doing so is less than the probability (p) of the benefit (b). For example, believing that the rustle in the grass is a dangerous predator when it is only the wind does not cost much, but believing that a dangerous predator is the wind may cost an animal its life.

The problem is that we are very poor at estimating such probabilities, so the cost of believing that the rustle in the grass is a dangerous predator when it is just the wind is relatively low compared with the opposite. Thus, there would have been a beneficial selection for believing that most patterns are real.

Through a series of complex formulas that include additional stimuli (wind in the trees) and prior events (past experience with predators and wind), the authors conclude that "the inability of individuals—human or otherwise—to assign causal probabilities to all sets of events that occur around them will often force them to lump causal associations with non-causal ones. From here, the evolutionary rationale for superstition is clear: natural selection will favour strategies that make many incorrect causal associations in order to establish those that are essential for survival and reproduction."

In support of a genetic selection model, Foster and Kokko note that "predators only avoid nonpoisonous snakes that mimic a poisonous species in areas where the poisonous species is common" and that even such simple organisms as "*Escherichia coli* cells will swim towards physiologically inert methylated aspartate presumably owing to an adaptation to favour true aspartate."

Such patternicities, then, mean that people believe weird things because of our evolved need to believe nonweird things. ■

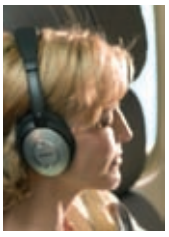
Michael Shermer is publisher of Skeptic *magazine (www.skeptic.com) and author of* Why People Believe Weird Things.

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Anti Gravity

Tabula Non Rasa

Einstein asked, "If a cluttered desk is a sign of a cluttered mind, then what is an empty desk a sign of?"

BY STEVE MIRSKY



Research report title: "A Stratigraphic Analysis of Desk Detritus."

Abstract: A multilayer investigation of various objects recovered from an archaeological dig site used for interpretation and dissemination of scientific information.

Discussion: On October 6, 2008, with a column overdue and a desk so messy the pile was starting to block the bottom of the computer screen, the author endeavored to kill two burdens with one stonewall, by removing and cataloguing multiple artifacts long stored on my desk.

The top layer consisted of various television remote controls, one AA battery charger, a one-gigabyte flash drive, a pair of bifocal sunglasses missing one arm, two pairs of intact reading glasses, and an ancient, two-megapixel digital camera. These were safely filed for future use.



Removal of the top layer unearthed a dictionary, which could come in handy in case the author is forced to construct a machicolation or use a machete because of any Machiavellian machinations by macho machinists. Also found were reimbursable receipts for expenditures made traveling to the last meeting of the American Association for the Advancement of Science in February. (Note to psychology experts: Why is doing expense reports such an onerous task given the large return available for a small time investment, and does this behavior relate to the overall economy being in the—consulting that book now—room with a fixture consisting of a large bowl and a water-flushing device?)

Next was a set of CDs called "300 Spectacular Sound Effects" used to punch up *Scientific American* podcasts. (Dating last use of a sound effect on the podcasts can set a minimum time for the presence of the CDs at this level of the dig.) Careful excavation then revealed a dust mask probably left over from a previous attempt to hit desktop.

Perhaps the highlight of the entire dig was the discovery of a fabulous pamphlet entitled "Have Scientists Been Wrong for 400 Years?" published by the Kansas-based Geocentric Bible Foundation, Inc., a group firmly convinced that the earth is stationary and at the center of the universe. "Ever since the scientific community adopted heliocentrism as fact," the brochure notes, "attempts have been made to prove it. Some of these attempts should have worked. Remarkably, not only has NOT ONE of these attempts produced the proof, but also the results of all of them are consistent with the hypothesis that ***the earth is at rest.***" (Capitalization, italics, boldface print and lunacy all found in original.)

Near the geocentricity document was the antidotal Darwin layer. A map of a New York Botanical Garden exhibit on Darwin sat directly above a Bank of England £10 note featuring Darwin's portrait. In light of the U.S. economic situation, the research team is evaluating the investment potential of strategically filing the note under any available mattress.

A key find was then made: a dated document, the April 24, 2008, issue of the *Onion*. The newspaper featured the front-page headline "NASA Intern Hoping To Go On Space Walk Before He Leaves In June." At this late date, it should be straightforward to discover whether 20-year-old Ryan Hodson, reputedly a cultural anthropology major at Columbia University, achieved his goal. (And whether he might have conducted any new research of interest to the Geocentric Bible Foundation.)

Underneath the *Onion* was another dated document, the April 13, 2006, edition of the *New York Post,* which included actual mathematics on the front page: "$(S + C) \times (B + F) / (T - V)$." This equation was touted as being the "formula for the perfect butt." Further elucidation and explanation of the variables (for example, B represents "bounciness," whereas V is the more rigorous "hip-to-waist ratio") was then found on page 3, under the heading, "Find Out If Your Booty Is A Beauty," featuring explanations by researchers identified as "tush-ologists." The accompanying article offered the caveat: "But [sic] science really settles nothing, says booty expert Sir-Mix-A-Lot." This issue of the *Post* was apparently saved to be used in a column for *Scientific American,* an intent now realized. Which will paradoxically encourage this writer to continue his slovenly ways. ■

PHOTOGRAPH BY FLYNN LARSEN; ILLUSTRATION BY MATT COLLINS

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MEET THE WORLD'S FIRST ECO-FRIENDLY SPARK PLUG

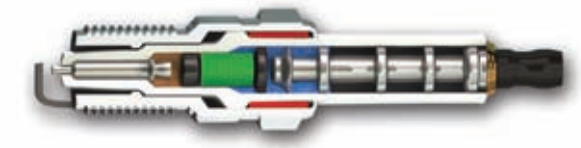
Actually, it's called a pulse plug—here's why its technology should be in your engine.

Until now, every gallon of gas you bought was ignited by a simple spark plug—an outmoded technology that has barely changed in 100 years. But now you can change to a new eco-friendly pulse plug that uses advanced technology to make every drop of gas burn better and cleaner.

The eight patents that the new pulse plug technology is based on come from pulsed power research at the world famous Sandia National Laboratories—and that's *definitely* rocket science.



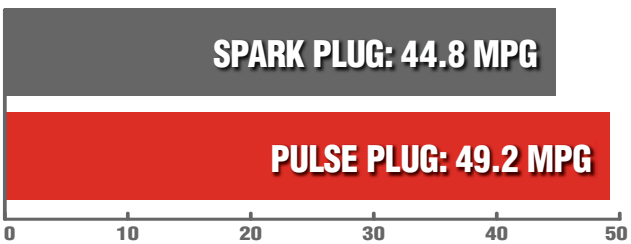
See the difference in technology: compare the cross section of a typical spark plug above, with that of the new pulse plug below.



Here's how it works: electrical energy from the engine's power coil is stored in the pulse plug's built-in capacitor. At the exact moment needed, that energy is released in an amazingly quick (two nanosecond), powerful, high-energy pulse.

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The Restless ENCELADUS



Wrinkled landscapes and spouting jets on Saturn's sixth-largest moon hint at underground waters

By Carolyn Porco

KEY CONCEPTS

- On the Saturnian moon Enceladus, jets of powdery snow and water vapor, laden with organic compounds, vent from the "tiger stripes," warm gashes in the surface. How can a body just over 500 kilometers across sustain such vigorous activity?
- The answer may be the presence of underground fluids, perhaps a sea, which would increase the efficiency of heating by tidal effects. Support for this idea has come from recent flybys.
- If Enceladus has liquid water, it joins Mars and Jupiter's moon Europa as one of the prime places in the solar system to look for extraterrestrial life.

—The Editors

When the Voyager 2 spacecraft sped through the Saturnian system more than a quarter of a century ago, it came within 90,000 kilometers of the moon Enceladus. Over the course of a few hours, its cameras returned a handful of images that confounded planetary scientists for years. Even by the diverse standards of Saturn's satellites, Enceladus was an outlier. Its icy surface was as white and bright as fresh snow, and whereas the other airless moons were heavily pocked with craters, Enceladus was mantled in places with extensive plains of smooth, uncratered terrain, a clear sign of past internally driven geologic activity. At just over 500 kilometers across, Enceladus seemed far too small to generate much heat on its own. Yet something unusual had clearly happened to this body to erase vast tracts of its cratering record so completely.

Voyager's brief encounter allowed no more than a cursory look, and, in hindsight, its imaging coverage of Enceladus was terribly unfortunate: a few medium-resolution images of the northern hemisphere, some low-resolution coverage in the south, and none of the south pole. We had no idea what we had missed.

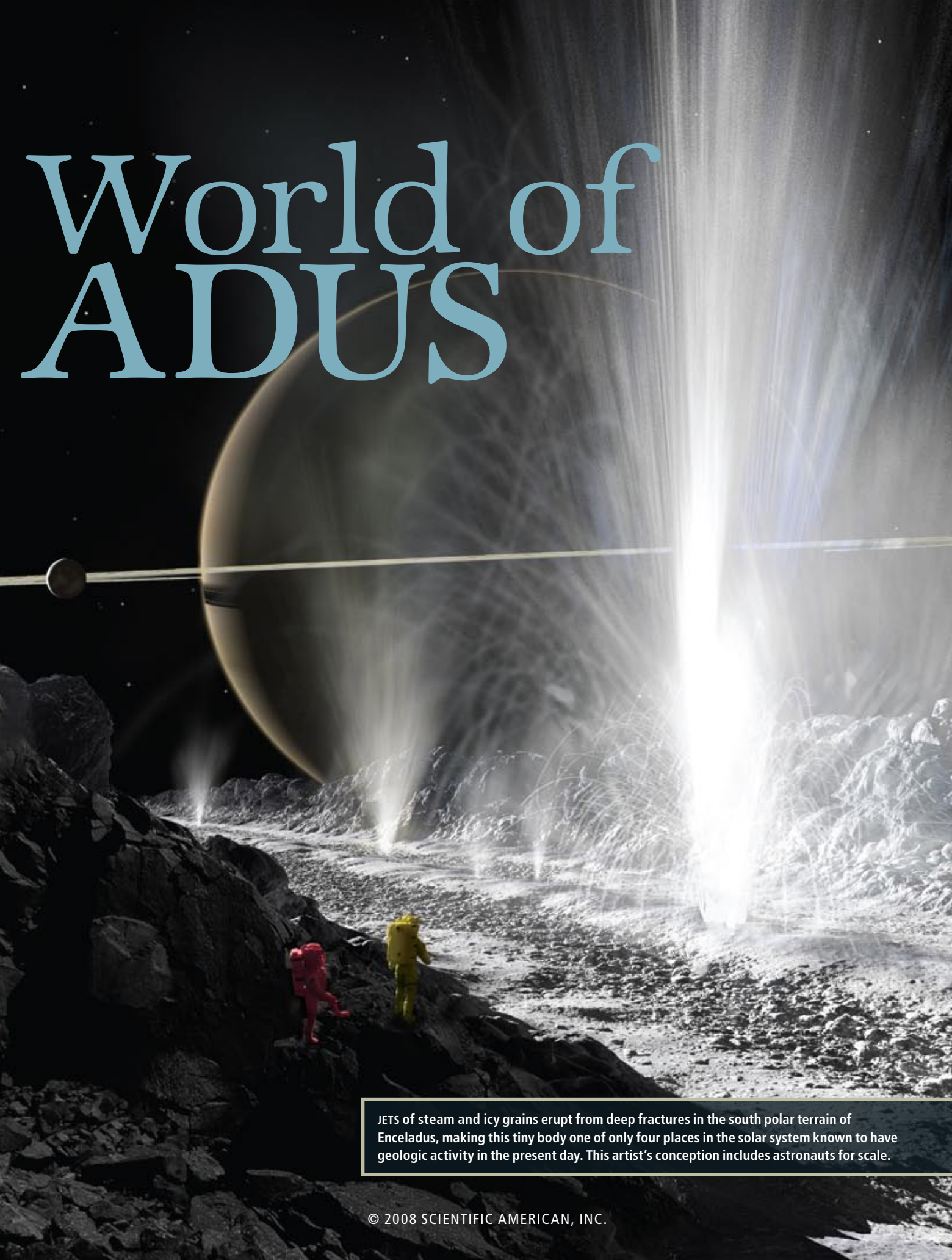
The interest generated by Voyager's visit made a comprehensive examination of Enceladus a cardinal goal of the Cassini mission to Saturn. Launched in 1997, Cassini spent seven long years crossing interplanetary space carrying the most sophisticated suite of instruments ever taken into the outer solar system. It finally pulled into port in the summer of 2004 [see "Saturn at Last!" by Jonathan I. Lunine; SCIENTIFIC AMERICAN, June 2004]. In December of that year it dropped a probe into the atmosphere of Titan, Saturn's largest moon, and then commenced its tour of the rest of the Saturnian system—not least Enceladus, which it has examined more closely than ever over the past several months.

What it found on this tectonically wracked little world has been a planetary explorer's dream, and now this tiny outpost tucked deep within a magnificent planetary system clear across the solar system has taken on a significance that belies its diminutive size. Enceladus not only has enough heat to drive surface-altering geologic activity but also is endowed with organic compounds and possibly underground channels or even seas of liquid water. Energy, organics, liquid water: these are the three requisites for life as we know it. In our explorations of this alien and faraway place, we have come face to face with an environment potentially suitable for living organisms. It does not get much better than this.

RON MILLER

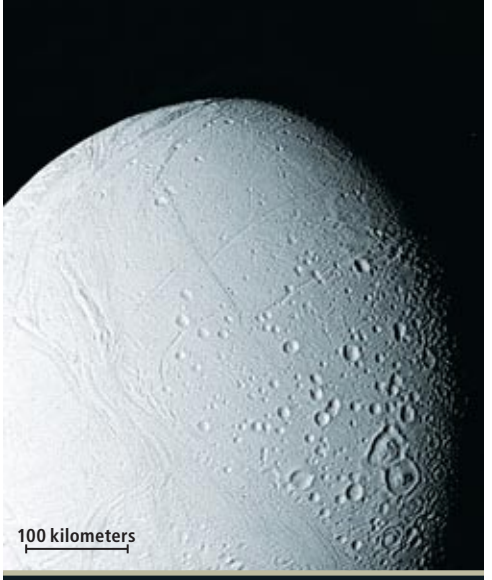
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World of ADUS

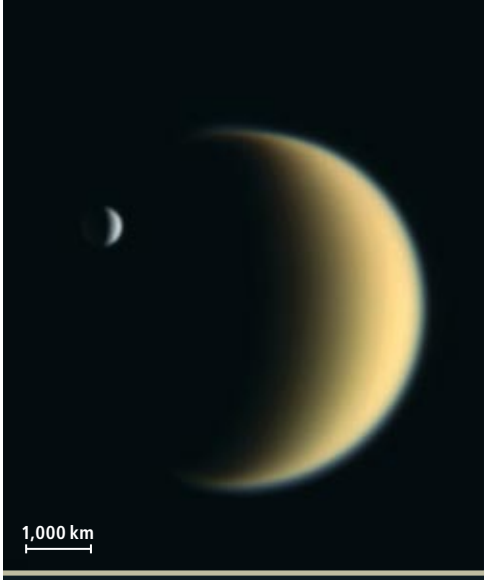


JETS of steam and icy grains erupt from deep fractures in the south polar terrain of Enceladus, making this tiny body one of only four places in the solar system known to have geologic activity in the present day. This artist's conception includes astronauts for scale.

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FIRST FLYBY of Enceladus, by the Voyager 2 spacecraft in 1981, produced images of limited coverage and mediocre resolution. The smooth areas indicated geologic activity in the recent past.



ENCELADUS (*left of center*) is a tenth the size of Saturn's largest moon, Titan. Bodies of its size lose their internal heat quickly; apart from Enceladus, they are all geologically dead. What keeps Enceladus active?

The Slow Reveal of Enceladus

The first hint, not unanimously appreciated at the time, that we were in for something very big emerged even before Cassini's first close encounter with Enceladus. In January 2005 our cameras took the first images of the moon backlit by the sun, a viewing geometry that planetary astronomers call high solar phase. Just as the dust that coats your car's windshield becomes dramatically more visible when you drive into the sun, so do the very fine particulates that are spread throughout the solar system when you look through them toward the sun. These viewing circumstances had proved very successful throughout the Voyager mission in revealing hard-to-see structures in rings and atmospheres of the outer planets and their moons, and they were key to the investigation of Enceladus.

The January images showed a flare protruding from the moon's south polar limb. No one needed to say it; we Voyager veterans were immediately reminded of the volcanic plumes rising above Jupiter's volcanic moon Io and the gossamer hazes in the atmosphere of Neptune's moon Triton. Some on the imaging team were convinced the flare was hard evidence that material was erupting from the south pole; others cautioned that the feature was probably one of those annoying camera artifacts that often turn up under sunward-facing conditions.

I was on the fence. Unfortunately, we were all too busy with planning future observations and writing scientific papers to undertake the kind of detailed analysis that might settle the matter. With no time for verification, I made the decision to say nothing publicly; I knew too well how embarrassing it would be to announce a discovery of a plume of material leaping off the surface of a moon that was supposed to be geologically dead, only to have to admit soon thereafter it was a smudge. Fortunately, we did not have long to wait.

The first two close flybys of Enceladus, in February and March, took the spacecraft sailing above and along the equator of Enceladus. Both returned spectacular results. The smooth plains seen by Voyager are not smooth at all. Instead they are extensively and finely fractured at subkilometer scales, in places crisscrossed by multiple generations of fractures and grooves, some linear, some curved. In other places, the surface is deeply scored with chasms half a kilometer deep. On an even finer scale, a spidery network of roughly parallel narrow cracks slices topographic forms into slabs. Enceladus has obviously seen multiple and distinct episodes of severe tectonic activity in its past—and has the scars to prove it.

The February flyby produced yet another high-solar-phase image showing a flare bigger and more dramatic than before. In addition, the magnetometer noticed that Saturn's magnetic field lines were being distorted as the planet's rotation carried them past Enceladus—a sign that the field lines were picking up heavy ions. The source of the ions appeared to be the moon's south pole. The evidence was mounting: our imaging artifacts were beginning to look like anything but.

The Cassini scientists presented the case to the project managers to get a better look—specifically, to lower the altitude of the July 2005

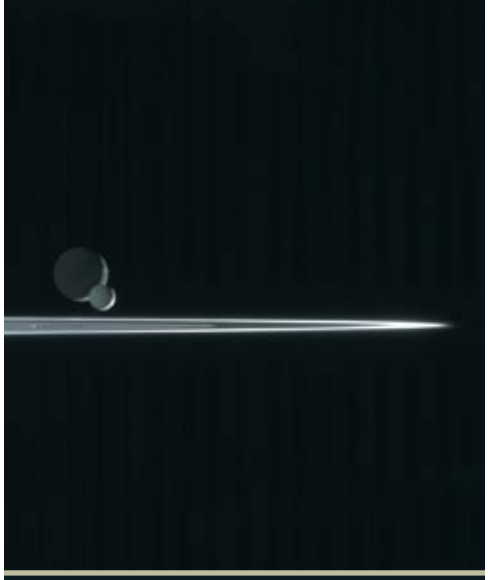
[THE AUTHOR]



Carolyn Porco **is leader of the Cassini imaging team and director of the Cassini Imaging Central Laboratory for Operations (CICLOPS). She was a member of the Voyager imaging team and from 2001 to 2003 served as vice chairperson of the Solar System Exploration Decadal Survey Committee of the National Academy of Sciences, which set priorities for planetary science. In January the American Humanist Association awarded her the Isaac Asimov Science Award, and in October** *Wired* **magazine named her one of 15 people the next president should listen to. Porco served as a consultant on the 1997 movie** *Contact* **and is now advising film director J. J. Abrams on the upcoming** *Star Trek* **movie.**

COURTESY OF CAROLYN PORCO AND ILM (*author and E.T.*); NASA/JPL/SPACE SCIENCE INSTITUTE (*Enceladus/Titan*)

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AS SEEN FROM CASSINI spacecraft, Enceladus slips in front of Dione, a larger and more distant moon whose gravity indirectly helps to drive Enceladus's activity. The outer part of Saturn's rings is in the foreground.

flyby from 1,000 kilometers to 168 kilometers. They agreed. On July 14, Cassini flew under the moon and over its high southern midlatitudes, giving us for the first time a clear view of the south pole, where lies a landscape as astonishing and geologically distinct as any seen anywhere in our solar system.

The terrain capping the south pole is a roughly circular region, completely crater-free and prominently etched by a handful of deep, parallel cracks we dubbed the "tiger stripes." Nearly evenly spaced, they run for 130 kilometers and terminate in hook-shaped bends. In between the stripes are brighter than average plains of finely grooved terrain, and the entire region is sharply demarcated at 55 degrees south latitude by a contiguous and meandering circumpolar boundary of concentric mountains and valleys. The boundary's meanders are spaced roughly every 45 degrees in longitude, with long cracks extending from some toward the equator into largely uncratered provinces.

The structure and placement of the mountains and valleys suggested to imaging team associate Paul Helfenstein of Cornell University that the boundary formed when the surface buckled as it was compressed horizontally along the north-south direction, like a convergent tectonic boundary resembling the Himalaya, and that the entire enclosed region is the Enceladus equivalent of the mid-Atlantic ridge—a spreading center where new surface is formed and pushes outward.

There is obviously a tale writ on the countenance of this little moon that tells of dramatic events in its past, but its present, we were about to find out, is more stunning by far. In its excursion over the outskirts of the south polar terrain, Cassini's dust analyzer picked up tiny particles, apparently coming from the region of the tiger stripes. Two other instruments detected water vapor, and one of them delivered the signature of carbon dioxide, nitrogen and methane. Cassini had passed through a tenuous cloud.

What is more, the thermal infrared imager sensed elevated temperatures along the fractures—possibly as high as 180 kelvins, well above the 70 kelvins that would be expected from simple heating by sunlight. These locales pump out an extraordinary 60 watts per square meter, many times more than the 2.5 watts per square meter of heat arising from Yellowstone's geothermal area. And smaller patches of surface, beyond the resolving power of the infrared instrument, could be even hotter.

By now we could not believe our good fortune to have stumbled on such a fascinating place. In quick response, the imaging team planned a special series of images to be taken in four months' time—late November 2005—looking over the south pole at high resolution and very high solar phase. In the meantime, a sufficient number of images of other moons, seen at similarly high phase, had accumulated, and with the help of image analysts in my group, I proved to the skeptics on our team that these had no flares whatsoever, and what we had on Enceladus was decidedly not an

DATA BANK: ENCELADUS

Mass: **1.08** × 10^{20} kilograms

Diameter: **504** kilometers

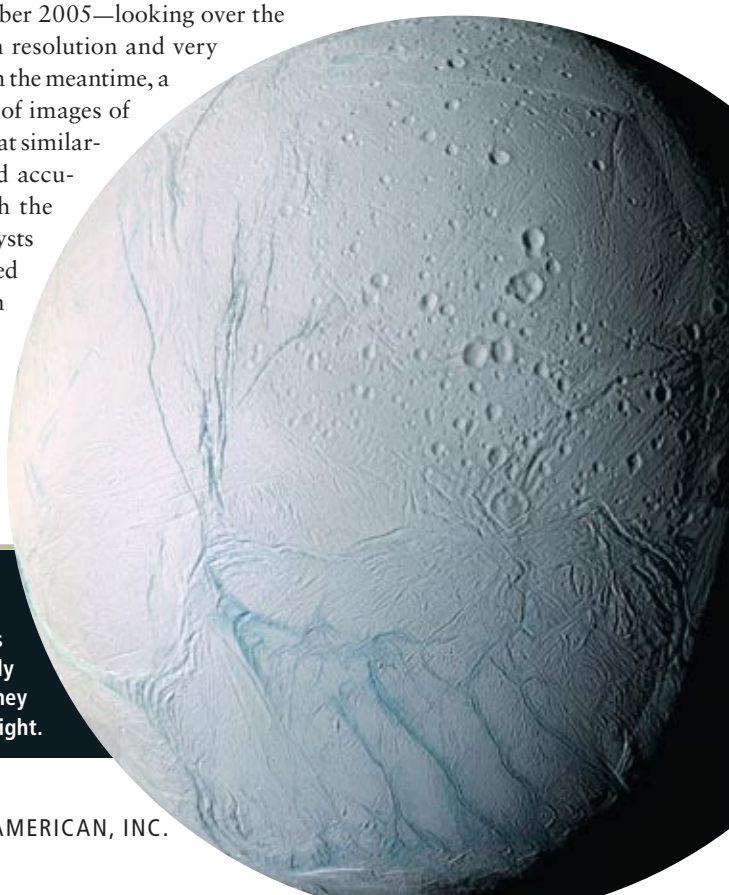
Density: **1.61** grams per cubic centimeter

Average orbital distance from Saturn: **238,037** km

Orbital period: **1.37** days

Eccentricity: **0.0047**

Inclination to Saturn's equator plane: **0.0083** degrees



SOUTHERN HEMISPHERE of Enceladus was revealed by Cassini for the first time in 2005. This mosaic of images shows the surface as it would appear if our vision extended into the infrared and ultraviolet. (To the unaided eye, the surface looks uniformly white.) The "tiger stripes" near the bottom are warm, geologically active gashes across the south polar terrain. Their bluish colors arise because they are coated with larger than average ice grains that absorb infrared light.

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2009 GL 320 BlueTEC, 2009 R 320 BlueTEC and 2009 ML 320 BlueTEC shown in optional Iridium Silver metallic paint. Additional optional equipment may be featured. **Road & Track* 10/08. ***Motor Trend* 10/08.



rural Vermont, calling the BlueTEC-powered ML's 27.5 mpg "impressive."* Likewise, on a test drive of its own, *Motor Trend* stated that it "returned an impressive average of 27.8 mpg during our cruise up the West Coast."** Test-drive one today and see how they can make your world a little greener. **MBUSA.com/thinkblue**

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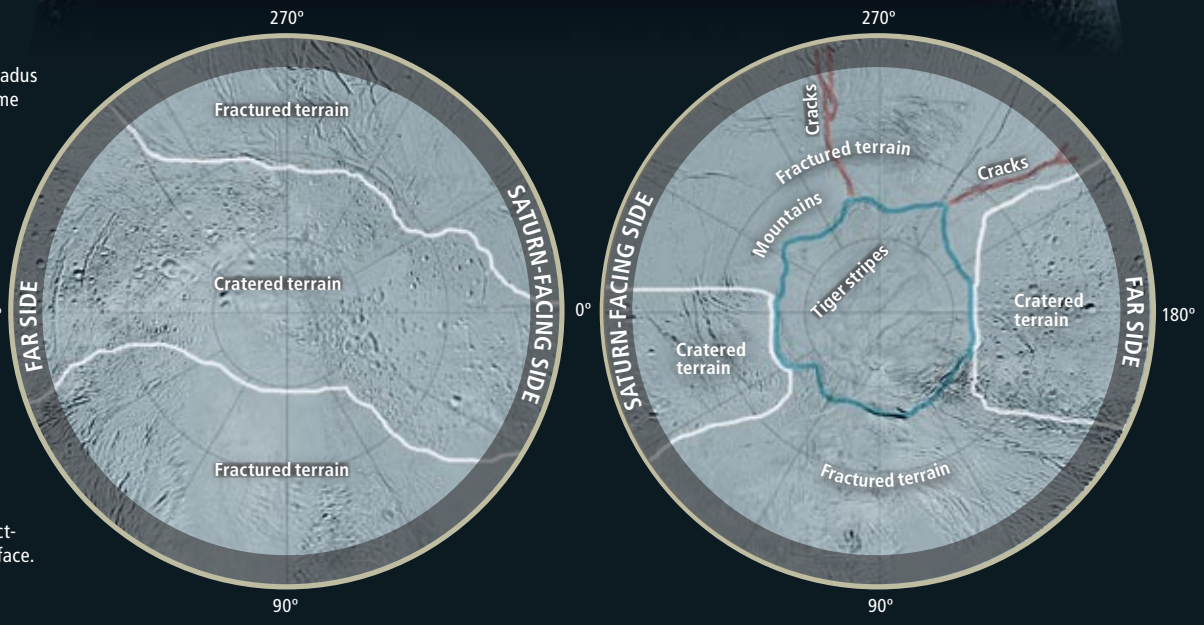
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[CASSINI SURFACE OBSERVATIONS]

The Many Faces of Enceladus

Few planetary scientists expected Enceladus to have the diversity of terrains it displays. Large parts of the northern hemisphere, imaged by Cassini (*above*) with six times the resolution of Voyager 2, are covered with craters and therefore must be older than the uncratered south polar terrain. But fractures, folds, ridges and troughs indicate that both hemispheres have been worked and reworked.

Like Earth's moon, Enceladus always presents the same face to its planet; the direction toward Saturn is defined as 0 degrees longitude. Cratered regions lie along the Saturn-Enceladus axis (at 0 and 180 degrees); fractured regions are perpendicular to it (90 and 270 degrees). The tiger stripes straddle the south pole and are surrounded by a mountain chain. These special orientations suggest that Saturn's gravitational influence has indirectly helped mold the surface.



artifact. Our fence-sitting days were over as we all realized we were looking at a plume of tiny particles that was absolutely gargantuan, extending at least several hundred kilometers above the moon's south pole.

On November 27 our series of striking black-and-white images of a crescent Enceladus finally arrived and showed, clear as day, a dozen or more distinct and narrow fountains of fine, icy particles jetting into space and feeding a faint but giant, flame-shaped plume towering over the south polar region. Later analysis by imaging team associate Joseph Spitale of the Space Science Institute and me showed that the jet sources coincide with the hottest locations on the tiger stripes—the first definitive evidence of a connection between warmth and active venting. Most of the particles fall back to the surface, but some have sufficient velocity to go into orbit around Saturn and are in fact responsible for creating its outermost ring, known as the E ring.

By anyone's measure, these images were a dramatic find: an incontrovertible indicium of current internal activity on an otherwise cold little moon. I could not help but feel an immediate kinship with those long ago who first set eyes on the geysering turmoil of Yellowstone.

Turning Up the Heat

The first Cassini science papers on Enceladus were published in early March 2006, and the craze began. Everyone began talking Enceladus. Cassini has since made a number of flybys of Enceladus, penetrating deeper into denser regions of the plume, reaching as low as 25 kilometers' altitude. During one very low flyby this past March, Cassini refined its measurements of the water vapor, nitrogen, carbon dioxide and methane, and, in addition, it discovered a smattering of other carbon-bearing compounds, such as acetylene and hydrogen cyanide, as well as trace amounts of ethane, propane, benzene, formaldehyde and other organics.

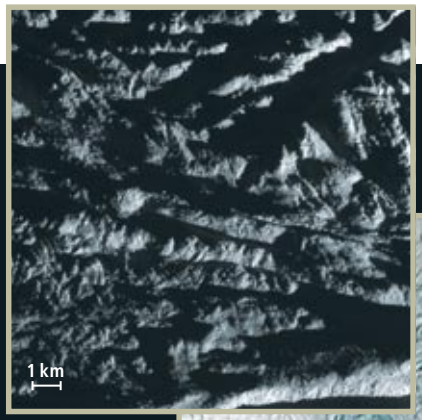
During another very close flyby in August, our cameras focused on the surface sources of the jets. The spacecraft's flyover was so fast that

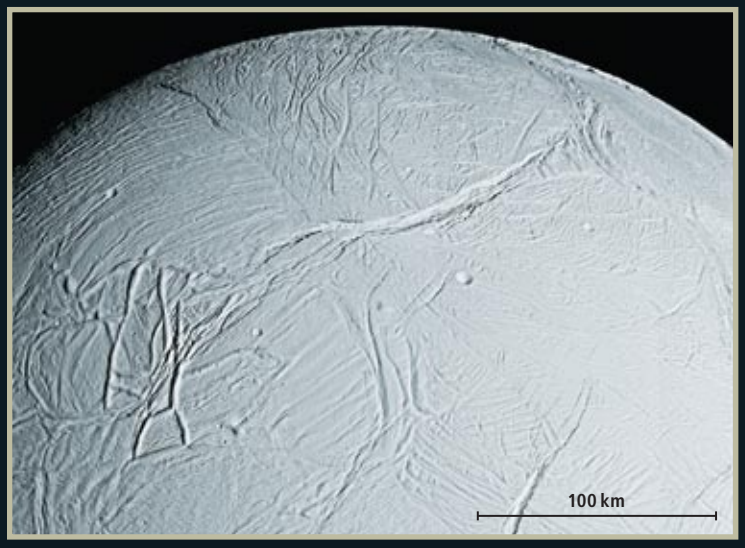
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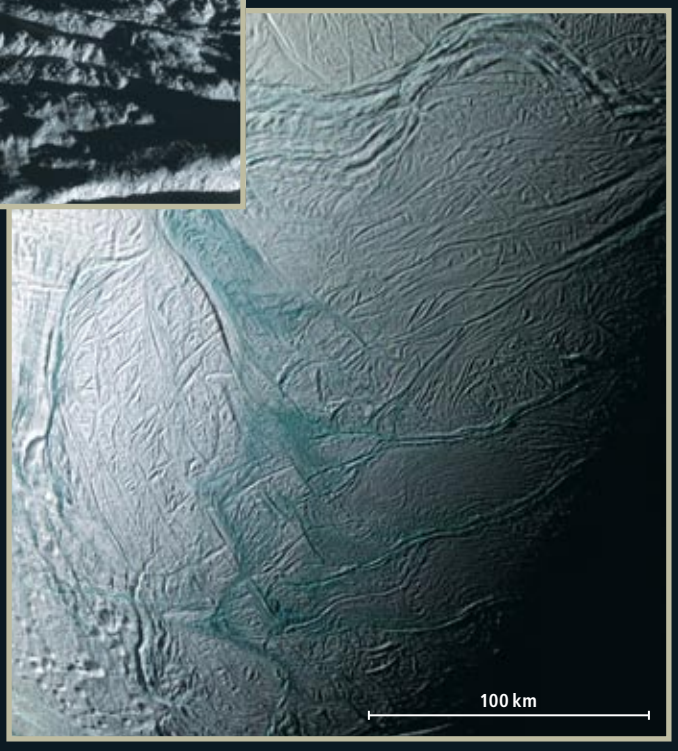
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On close inspection by Cassini, large regions on Enceladus that looked smooth to Voyager are actually highly textured (*below*). Deep chasms extend northward into fractured terrains. Even craters are fractured, sliced and often degraded (*left*).







Close-up of the tiger-stripe region shows blocks of ice the size of houses (*top*). Surrounding the stripes is a sinuous circumpolar chain of mountains that may be the Enceladan tectonic equivalent of the Himalaya (*above*).

a special camera-panning technique, akin to skeet shooting, had to be devised to avoid motion smear. Perfectly executed, the sequence revealed the tiger stripes to be as deep as 300 meters, with V-shaped walls and blocks of ice the size of houses strewn across their flanks and beyond. Areas along the flanks appear smoother than average—probably blankets of freshly fallen snow.

Unexpectedly, the immediate vicinity of each vent is not obviously distinguishable from other places along the fractures. We preliminarily concluded that no one vent stays active very long. Ice plugs grow from condensing vapor and choke off the vent before it can significantly alter the ground around it. At that point, pressure forces open a new vent somewhere else along the fracture, it, too, becomes choked off, and on it goes. A long time-lapse movie might show migration of jets up and down long linear extents of the fracture.

Apart from giving us a window on a breathtaking geologic phenomenon, the images have also yielded precise measurements of Enceladus's size and shape. Together with the moon's mass, derived from its gravitational perturbations to Cassini's trajectory during their close encounters, this information has revealed that Enceladus is the rockiest of Saturn's major moons. Its average density of 1.6 grams per cubic centimeter implies that rock is 60 percent of the moon's mass, and chances are good that the rock is concentrated in a rocky core surrounded by a mantle of water ice several tens of kilometers thick.

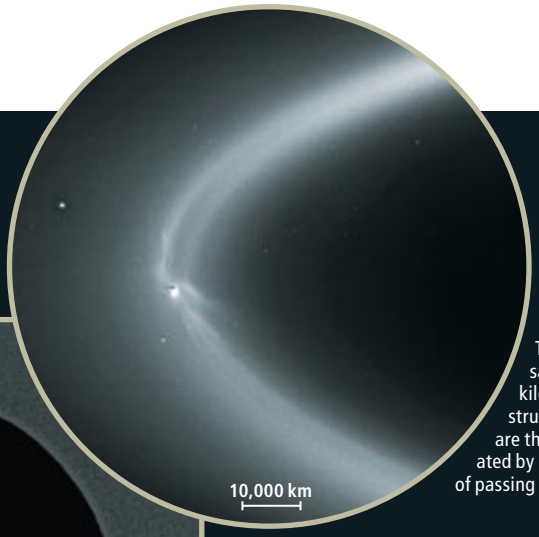
On Earth, rock contains radioactive substances that produce heat. The same is undoubtedly true on Enceladus. But even all that rock is insufficient to produce the observed heat. The only other plausible source of warmth is tidal heating. Just as the gravity exerted by the sun and Earth's moon deforms our planet slightly, creating the ocean tides, Saturn's gravity deforms Enceladus. Enceladus has a noncircular orbit; its distance from Saturn varies. The closer it gets, the more it is deformed. This daily varia-

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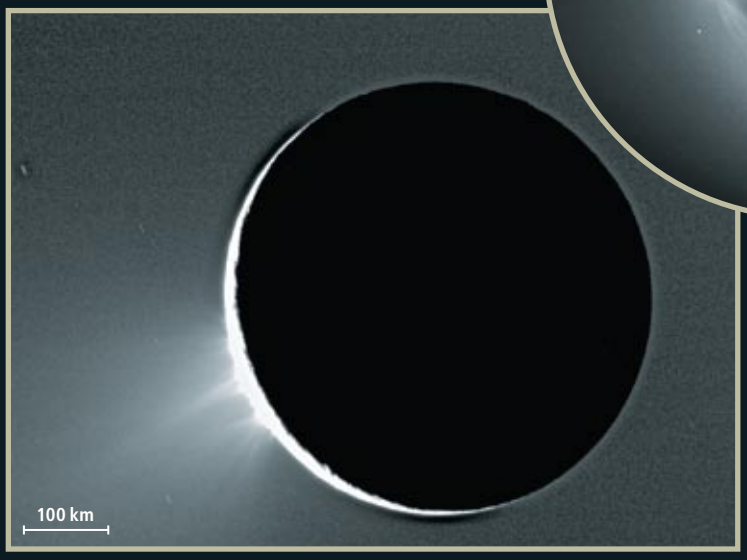
[CASSINI GEYSER OBSERVATIONS]

Hot Springs on a Cold Moon

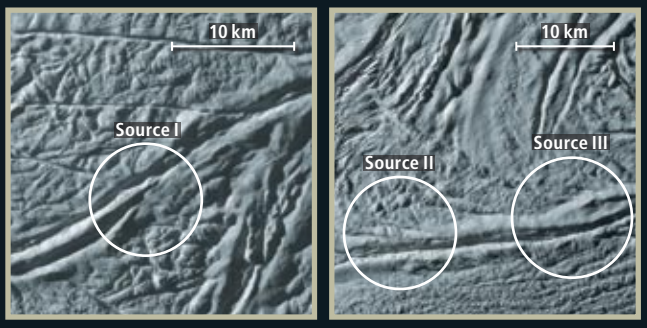
Shooting out of the south pole are jets of material, which feed a broad, towering plume.



The jets feed Saturn's E ring, as Cassini saw from a distance of about two million kilometers. Some of the long, tendril-like structures seen in the vicinity of Enceladus are the extensions of the jets. Others are created by Enceladus's gravitational perturbations of passing particles in the E ring.



The tiny, icy grains sprayed into space are easiest to see when backlit by the sun. Mountains and valleys are visible along the edge of this silhouette.



The jets can be traced to specific locations on the tiger stripes. Oddly, these locations do not obviously differ from other parts of the stripes.

tion gives rise to flexure and internal heating. Gravity may also play a role in forming the surface features. The tiger stripes are angled 45 degrees from the direction to Saturn—an orientation that tidal forces would naturally explain.

The magnitude of heating depends not only on the orbital eccentricity—the degree to which the orbit departs from a perfectly circular shape—but also on the consistency of the moon's interior. A very rigid body would resist deformation. A perfectly elastic body would deform but not dissipate energy as heat. A pliable moon consisting of viscous material would yield and heat up, as would a moon that is partly rigid but shot through with cracks, so that slabs of ice rub against one another and generate heat by friction. The heating need not occur uniformly throughout the moon. It can be concentrated in the outer shell of ice or in limited regions within the outer shell such as cracks.

Typically tidal heating tends to shut itself off. The material in a moon takes time to deform, so the distortion is always out of alignment with the forces that produce it. The result is a gravitational torque that alters the moon's orbital motion and gradually circularizes the orbit. The tidal stresses stop varying, the moon settles into a fixed shape, and heating ceases. Enceladus, however, remains in an elliptical orbit because of an orbital resonance with its bigger sibling moon Dione. For every two orbits Enceladus makes, Dione makes one. This synchrony allows periodic gravitational kicks from Dione to act coherently over time and keep Enceladus's orbit out-of-round.

Yet even these special circumstances are not enough. Jennifer Meyer and Jack Wisdom of the Massachusetts Institute of Technology have examined the orbital configuration of Enceladus and found that the amount of tidal energy being injected into the body falls short of the energy coming out of Enceladus's south pole by a factor of five. This result is completely independent of how tidal energy is internally dissipated. Enceladus, in its present orbit, simply lacks enough energy to explain its heat output.

The Silly Putty Moon

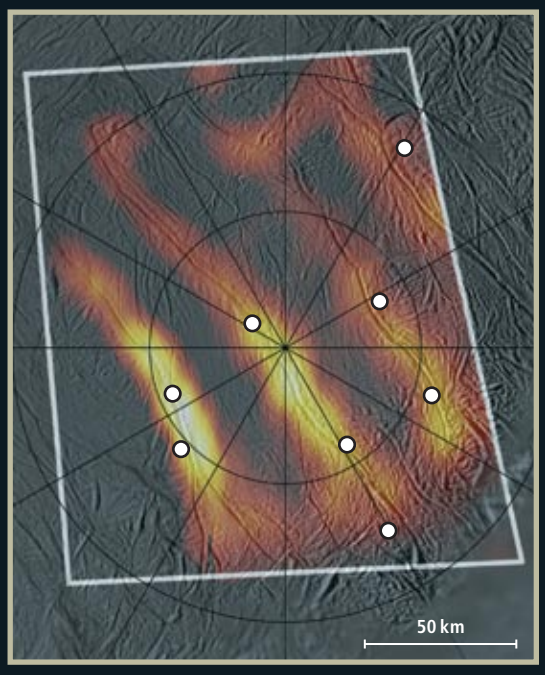
The paradox arises only if you assume that Enceladus's present-day tidal heating should precisely match its present-day heat output. What if Enceladus is still giving off heat from an earlier heating episode? One possible scenario, first examined in 1986 for Io by Greg Ojakangas and David Stevenson, both then at the California Institute of Technology, is that the orbit of a

LIFE ON ENCELADUS?

Enceladus has three of the essential requirements for life: liquid water, organic compounds and energy. Have these putative habitable conditions persisted long enough for life to develop there? No one knows how long it would take. Judging from the geologic record, microbes emerged on Earth very quickly in geologic terms: within a few hundred million years (or even sooner) after the planet's final throes of formation.

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A thermal map shows temperatures up to 180 kelvins along the stripes, much too hot to be explained by solar heating. The jets originate in the very hottest regions (*white circles*).

moon and the consistency of its interior can play off each other, leading to a cyclic variation of both orbital eccentricity and heat output.

Imagine starting with a cold, mostly rigid Enceladus in a nearly circular orbit. The rate of tidal heating is relatively low. Dione forces the orbital eccentricity to increase, which leads to greater flexure and viscous heating in the ice shell. The eccentricity and heating continue to increase until, at some point, the heating rate exceeds the ability of the moon to lose its heat. The internal temperature then starts to rise, and the interior material becomes softer and less rigid, which leads to yet more tidal heating. In another possible oscillatory scheme, the moon becomes less rigid not because it becomes more pliable but because cracks develop. Tidal stresses fracture the ice and cause shear motions. Friction between the crack surfaces leads to tidal energy dissipation and heating along the cracks.

In either case, the additional dissipation causes the moon's orbit to become more circular, and eventually the trend reverses; tidal heating begins to decrease and eventually falls below the rate of heat loss from the surface. The moon begins to cool off and either the ice returns to being stiff or, in the second scenario, the cracks heal. The cycle, which can take tens of millions of years, then begins anew. The idea illustrates how we might happen on a moon at a time when its heat input and output are not in a steady state. In such an oscillatory scheme, the energy input and output balance only over the full cycle. At any given instant, the moon's heat output might be found to be above or below average—and above or below its instantaneous heating rate.

Ojakangas and Stevenson have shown that a cycle mediated by the temperature dependence of the viscosity of ice may work for Io, which, like Enceladus, has a mismatch of heat input and output. Unfortunately, it cannot work for Enceladus: Meyer and Wisdom have concluded that the moon is not sufficiently massive. The crack-mediated cycle may be possible but has yet to be fully investigated.

What Lies Beneath?

Gabriel Tobie of the University of Nantes in France and his collaborators have examined another possible solution: that a zone of weakness at the south pole can focus tidal energy there and sustain itself through time. They simulated the response of Enceladus to tidal forcing assuming that underlying the south pole is a sector of low viscosity, making this part of Enceladus more pliable than the rest. This model can reproduce the observed heat output, but only under two conditions that revolutionize our view of Enceladus.

First, the ice in the zone must be warm—near its melting point—and, second, there must be a liquid layer wedged between the overlying ice shell and the rocky core. This layer must underlie nearly the entire southern hemisphere. Without it, not only would flexure and hence viscous heating be insufficient, it would tend to occur at the equator rather than the pole.

The idea of a subsurface sea becomes all the more compelling when one considers that Enceladus's south polar cap is actually a half-kilometer-deep basin carved into the moon's overall figure. According to work by Geoffrey Collins of Wheaton College and Jason Goodman of the Woods Hole Oceanographic Institution, this basin could be the surface expression of a subsurface sea. Liquid water is denser than ice, so the total volume of water in this region is lower. In essence, the entire south polar region is a giant sinkhole.

In fact, a sea could indirectly account for much of Enceladus's geologic diversity. Isamu Matsuyama of the Carnegie Institution of Wash-

WHY THE SOUTH POLE?

How did geologic activity on Enceladus come to be concentrated at the south pole? Chance may be the answer. Perhaps an event in the moon's past—a meteor impact into the moon, like those that created the huge basins on other moons of Saturn, such as Iapetus and Tethys—initially cracked or otherwise weakened its outer ice shell, focusing tidal energy there. The ice shell might then have slid around over time in a process known as true polar wander, in which case centrifugal forces would have shifted low-density regions to the poles. Paul Helfenstein of Cornell University has found evidence for such movement: a region called Sarandib Planitia near the equator looks like an eroded version of the south polar terrain. It might once have been at the pole and since moved to its present location.

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ington and Francis Nimmo of the University of California, Santa Cruz, have shown that the position and orientation of the moon's major geologic features—in particular, the north-south trending cracks and the circumpolar mountains—are a sign that the moon's ice shell has slipped relative to its spin axis. The moon acts like a giant gyroscope whose outer shell is free to pivot around.

This idea would explain why the geologically active region is exactly at the south pole: a warm region, with lower than average density, will naturally drift toward the axis of rotation. Furthermore, a warmer zone under the south pole would rise in convective motion under the uppermost brittle layer of the ice shell, explaining the spreading-center characteristics of the south polar terrain. For the ice shell to move in this way requires a liquid layer to decouple the ice from the deeper interior.

The full cause of Enceladus's activity may be a combination of these effects. If Enceladus undergoes a crack-mediated heating cycle and if the rate of tidal deformation of the moon's outer ice shell is fast enough, cracks may propagate into the underlying ductile warm zone and perhaps all the way down to the sea. Frictional heating within these fractures would contribute to the overall viscous heating under the south pole. Ice might melt along the deep cracks, and the meltwater would substantially enhance the heating rate. In this way, an underground sea might be self-sustaining, with the liquid water in the overlying shell supplying the sea below. As long as the sea never completely freezes during the cooling phase of the cycle, the whole process would continue as long as Enceladus remains in orbital synchrony with Dione.

To top it off, liquid water could naturally account for the observed eruptions. Michael Manga of the University of California, Berkeley, has shown that partial freezing of an underground sea would increase its pressure and force liquid up. As the pressure is released on ascent, dissolved gases such as carbon dioxide would come out of solution and form bubbles, which, like shaking a bottle of champagne, can assist the rising liquid. If liquid is indeed making it all the way to the surface, it provides a ready answer to the question of how heat gets from where it is produced, deep within the moon, to the surface: flowing water is very efficient in carrying heat. It also implies that the jets in fact are geysers and originate in subterranean liquid reservoirs.

Enceladus as the Abode of Life

We are still testing and refining our notions about how Enceladus has come to be the way it is. But in all, it is almost unavoidable that liquid water is present somewhere below its surface. If so, we face the thrilling possibility that within this little moon is an environment where life, or at least its precursor steps, may be stirring. Everything life needs appears to be available: liquid water, the requisite chemical elements and excess energy. The best analogues for an Enceladan ecosystem are terrestrial subsurface volcanic strata where liquid water circulates around hot rocks, in the complete absence of sunlight and anything produced by sunlight. Here are found organisms that consume either hydrogen and carbon dioxide, creating methane, or hydro-

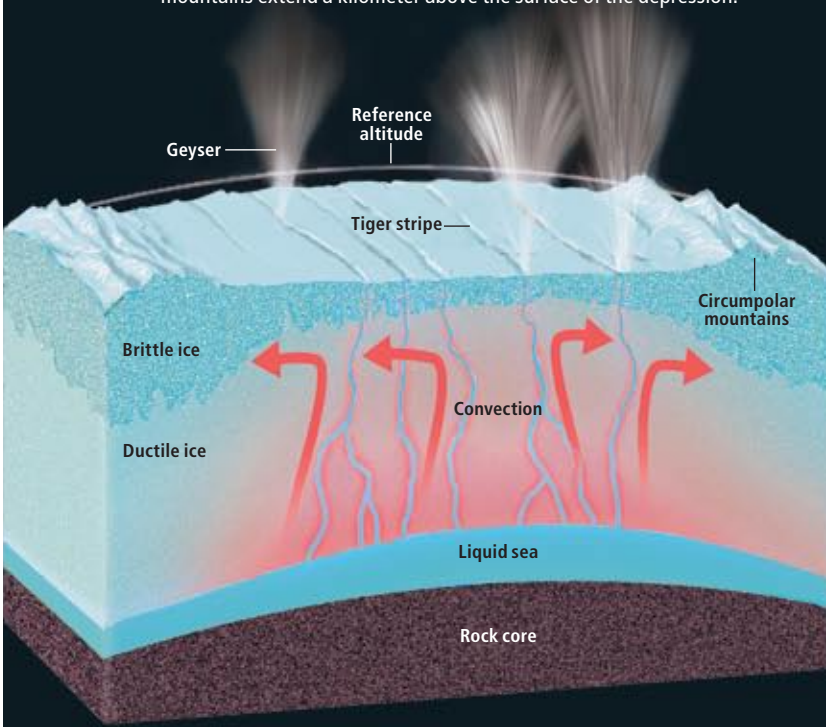
[INTERIOR OF ENCELADUS]

Waterworld

The jets and warm temperatures strongly suggest that Enceladus has underground liquid water. Not only do the jets spout water ice particles and vapor, but the intense heating that drives them seems to require liquid water to facilitate tidal energy deposition by Saturn.

Enceladus may consist of a rock core surrounded by a thick layer of water ice. The entire south polar area is a half-kilometer-deep depression in the moon's figure, perhaps the result of a subsurface sea. Circumpolar mountains extend a kilometer above the surface of the depression.





From a liquid sea at the base of the ice, water under pressure, helped by dissolved gases, could flow up through deep cracks and vent at the surface. Friction within the cracks might create enough heat to melt ice. Convection currents below the south polar terrain could cause the surface to spread outward and create the circumpolar mountains.

RON MILLER

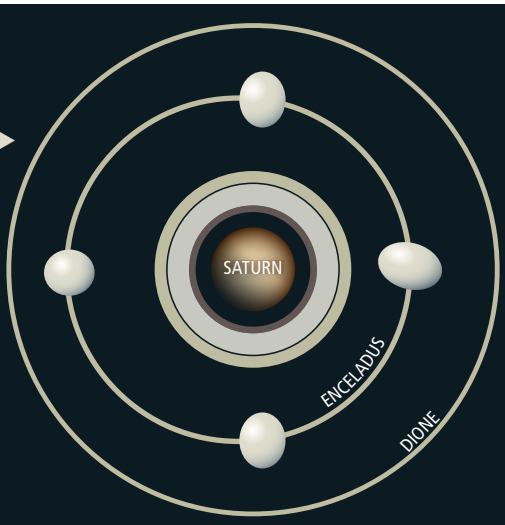
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[SOURCE OF ENERGY]

Turning the Tide

TIDAL ENERGY INPUT ▶

In the same process that produces the ocean tides on Earth, Saturn's gravity stretches Enceladus into a slightly oblong shape. The amount of stretching varies as Enceladus revolves around Saturn because its orbit is not perfectly circular. The resulting stresses heat the interior. This process also tends to circularize the orbit, but the gravity of another Saturnian moon, Dione, keeps the orbit noncircular.



COLD SATELLITE
- Nearly circular orbit
- Rigid interior
- Minimal tidal stressing and heating

ORBITAL ELONGATION
- Orbit elongated by Dione interaction
- Tidal stresses increase
- Cracks form

HOT SATELLITE
- Frictional heating occurs along cracks
- Heat input exceeds loss
- Possible melting of ice along cracks

ENERGY DISSIPATION
- Heating dissipates orbital energy
- Orbit begins to circularize
- Stresses diminish and cracks seal up

◀ HEATING CYCLE

The present amount of tidal heating is too weak to power the observed geologic activity. One resolution of this discrepancy is that Enceladus is living off an injection of heat thousands or millions of years ago. The heating could have been stronger in the past if the orbit was even more noncircular. That could happen because the degree of noncircularity, the amount of interior fracturing and the strength of heating all depend on one another—allowing for a cycle in which all three vary.

gen and sulfate—all powered not by the sun but by Earth's own internal heat.

The Enceladus of today is very much the child of yesterday, and we are only just beginning to assemble its past from the precious clues littered on its surface. Many questions remain that even Cassini, as capable as it is, cannot answer—questions that are and will remain beyond our reach until we set a specially equipped spacecraft in orbit around the moon or a lander down on its surface. An orbiter could fully map the moon's gravity field and surface topography, revealing its internal distribution of mass, including any subsurface liquid layer. A small lander, equipped with a seismometer, could detect the rumblings of underground liquids.

The sheer cost and long development time of complex missions mean we have to be very selective in where we go. Many scientists are eager to return to Europa, because this moon of Jupiter is also apparently endowed with a subterranean ocean that could harbor extraterrestrial life [see "The Hidden Ocean of Europa," by Robert T. Pappalardo, James W. Head and Ronald Greeley; Scientific American, October 1999]. To my mind, however, further exploration of Enceladus is so much more promising. Because scientists do not know of any active vents on Europa, sampling its interior to test for the presence of an ecosystem would require drilling to great depths, an enterprise so challenging it will surely not happen in our lifetime. By comparison, to sample the interior of Enceladus, all you have to do is fly through the plume or land on the south polar terrain, look up and stick your tongue out.

In addition, because Saturn's magnetosphere is anemic compared with Jupiter's, a spacecraft on or around Enceladus does not have to contend with a severe, mission-limiting radiation field, as would a Europa orbiter. Finally, a journey to Enceladus could permit tandem exploration of Titan, another Saturnian destination offering a possible look at life's chemical beginnings [see "The Mystery of Methane on Mars and Titan," by Sushil K. Atreya; Scientific American, May 2007].

For now, we delight in knowing that humanity's first in-depth survey of Saturn and its retinue of worlds has uncovered something wondrous at the southern tip of this small, enigmatic moon: a fantastic and restless place of deep, icy chasms and soaring ghostly fountains, a rare realm whose discovery has rewarded both mind and soul. As planetary explorers, we could not have asked for more. ■

MORE TO EXPLORE

Cassini Observes the Active South Pole of Enceladus. C. C. Porco et al. in *Science,* Vol. 311, pages 1393–1401; March 10, 2006.

Life on a Tiny Moon: NOVA Voyage to the Mystery Moon. Interview with Carolyn Porco, March 2006. **www.pbs.org/wgbh/nova/titan/porco.html**

Cassini: The First One Thousand Days. Carolyn C. Porco in *American Scientist,* Vol. 95, No. 4, pages 334–341; July/August 2007.

Solid Tidal Friction above a Liquid Water Reservoir as the Origin of the South Pole Hotspot on Enceladus. G. Tobie, O. Čadek and C. Sotin in *Icarus,* Vol. 196, No. 2, pages 642–652; August 2008.

The Possible Origin and Persistence of Life on Enceladus and Detection of Biomarkers in the Plume. C. P. McKay et al. in *Astrobiology,* Vol. 8, No. 5, pages 909–922; October 2008.

MELISSA THOMAS

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A NEW MOLECULE OF LIFE?

Peptide nucleic acid, a synthetic hybrid of protein and DNA, could form the basis of a new class of drugs—and of artificial life unlike anything found in nature

By Peter E. Nielsen

KEY CONCEPTS

- A synthetic molecule called peptide nucleic acid (PNA) combines the information-storage properties of DNA with the chemical stability of a proteinlike backbone.
- Drugs based on PNA would achieve therapeutic effects by binding to specific base sequences of DNA or RNA, repressing or promoting the corresponding gene.
- Some researchers working to construct artificial life-forms out of mixtures of chemicals are also considering PNA as a useful ingredient for their designs.
- PNA-like molecules may have served as primordial genetic material at the origin of life.

—The Editors

For all the magnificent diversity of life on this planet, ranging from tiny bacteria to majestic blue whales, from sunshine-harvesting plants to mineral-digesting endoliths miles underground, only one kind of "life as we know it" exists. All these organisms are based on nucleic acids—DNA and RNA—and proteins, working together more or less as described by the so-called central dogma of molecular biology: DNA stores information that is transcribed into RNA, which then serves as a template for producing a protein. The proteins, in turn, serve as important structural elements in tissues and, as enzymes, are the cell's workhorses.

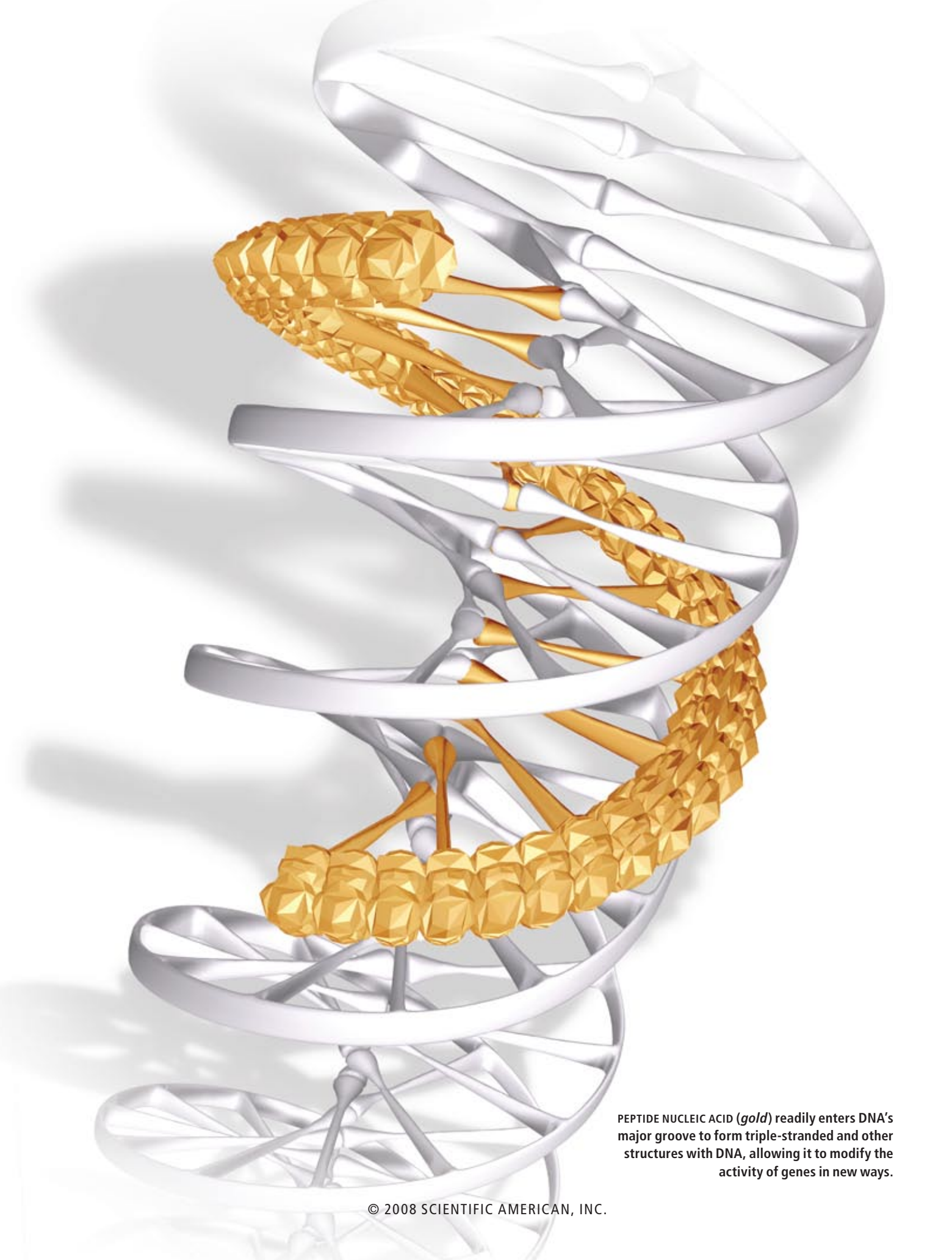
Yet scientists dream of synthesizing life that is utterly alien to this world—both to better understand the minimum components required for life (as part of the quest to uncover the essence of life and how life originated on earth) and, frankly, to see if they can do it. That is, they hope to put together a novel combination of molecules that can self-organize, metabolize (make use of an energy source), grow, reproduce and evolve.

A molecule that some researchers study in pursuit of this vision is peptide nucleic acid (PNA), which mimics the information-storing features of DNA and RNA but is built on a proteinlike backbone that is simpler and sturdier than their sugar-phosphate backbones. My group developed PNA more than 15 years ago in the course of a project with a rather more immediately useful goal than the creation of unprecedented life-forms. We sought to design drugs that would work by acting on the DNA composing specific genes, to either block or enhance the gene's expression (the production of the protein it encodes). Such drugs would be conceptually similar to "antisense" compounds, such as short DNA or RNA strands that bind to a specific RNA sequence to interfere with the production of disease-related proteins [see "Hitting the Genetic Off Switch," by Gary Stix; Scientific American, October 2004].

PNA's unique properties potentially give it several advantages over antisense DNAs and RNAs, including more versatility in binding to DNA as well as RNA, stronger binding to its target and greater chemical stability in the enzyme-laden cellular environment. Many studies have demonstrated PNA's suitability for modifying gene expression, mostly in molecular test-tube experiments and in cell cultures. Studies in animals have begun, as has research on ways to transform PNA into drugs that can readily enter a person's cells from the bloodstream.

JEAN-FRANCOIS PODEVIN

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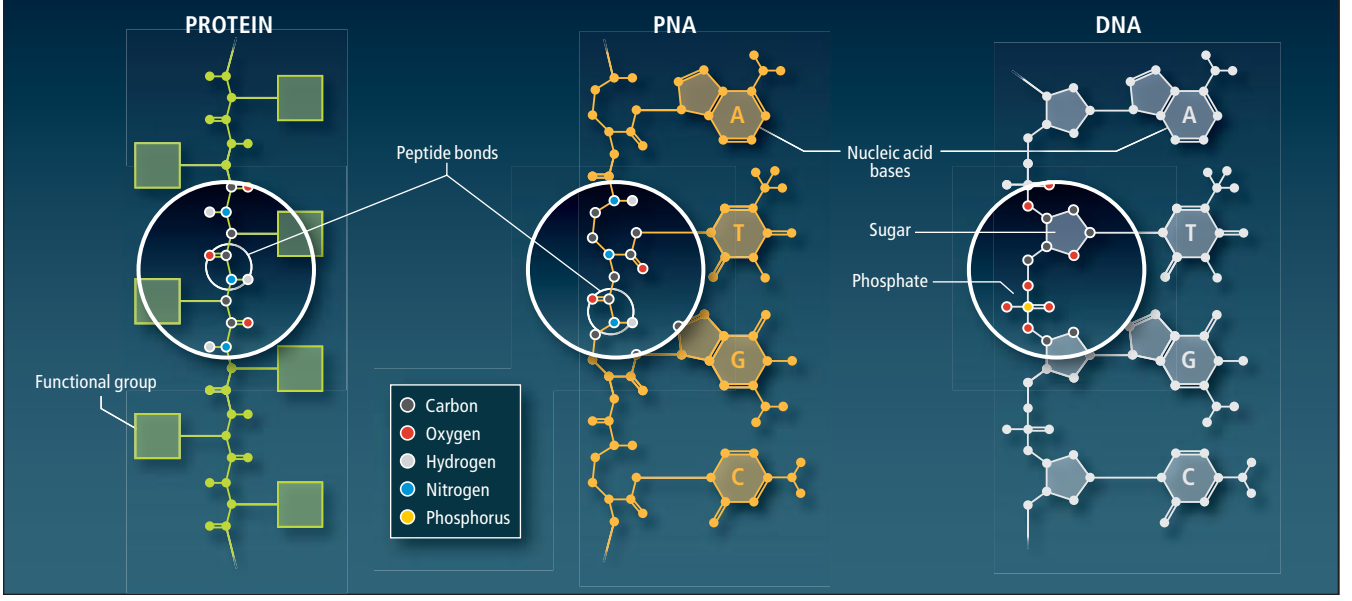
PEPTIDE NUCLEIC ACID (*gold*) readily enters DNA's major groove to form triple-stranded and other structures with DNA, allowing it to modify the activity of genes in new ways.

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[THE MOLECULE]

PNA: A PROTEIN-DNA HYBRID

Peptide nucleic acid (PNA) combines features of protein and DNA. The backbone of PNA consists of relatively simple units linked by sturdy peptide bonds (*box*), as in a protein, unlike the less stable and negatively charged phosphate-sugar backbone of DNA. Each unit of PNA carries a nucleic acid base, as in a strand of DNA.



[THE AUTHOR]



Peter E. Nielsen heads the Center for Biomolecular Recognition in the department of cellular and molecular medicine at the University of Copenhagen. He has been affiliated with the university since 1980, when he received his Ph.D. there. As well as being one of the inventors of peptide nucleic acid, he co-founded two biotechnology companies in Denmark (Pantheco and PNA Diagnostics, now part of Santaris and Applied Biosystems, respectively) to develop applications of the molecule, and he has more than 20 related patents and patent applications.

In addition to fomenting exciting medical research, these amazing molecules have inspired speculations relating to the origin of life on earth. Some scientists have suggested that PNAs or a very similar molecule may have formed the basis of an early kind of life at a time before proteins, DNA and RNA had evolved. Perhaps rather than creating novel life, artificial-life researchers will be re-creating our earliest ancestors.

Into the Groove

The story of PNA's discovery begins in the early 1990s. To generate drugs with broader capabilities than antisense RNA, my colleagues Michael Egholm, Rolf H. Berg, and Ole Buchardt and I wanted to develop small molecules able to recognize double-stranded, or duplex, DNA having specific sequences of bases—no easy task. The difficulty has to do with the structure of the familiar DNA double helix.

It is the bases—thymine (T), adenine (A), cytosine (C) and guanine (G)—that store information in DNA. (In RNA, thymine is replaced by the very similar molecule uracil, or U.) Pairs of these bases joined by hydrogen bonds form the "rungs" of the familiar DNA "ladder." C binds with G, and A binds with T, in what is called Watson-Crick base-pairing. A compound that binds with a stretch of double-helical DNA having a characteristic base sequence would therefore be one that acts on any gene containing that particular sequence of bases on one of its strands.

The task of recognition is relatively easy if a compound has to find a particular base sequence on *single*-stranded DNA or RNA. If two nucleic acid strands have complementary sequences, standard base-pairing can zip the two strands together. Thus, if one knows the sequence of a gene—from Human Genome Project data, for instance—producing a molecule to latch onto a section of the gene in a single strand is as simple as synthesizing the complementary sequence.

In duplex DNA, however, the task of recognizing a sequence is more challenging because the atoms responsible for Watson-Crick pairing are already involved in the hydrogen bonds linking the two strands together and thus are not available for linking with another molecule. Yet cells contain numerous so-called gene-regulatory proteins that recognize sequences in duplex DNA to carry out their function of controlling gene expression. So the feat can be accomplished. If my group could find molecules capable of the task, the molecules could potentially serve as gene-regulating drugs.

Gene expression takes place in two stages. First, in transcription, an enzyme constructs

COURTESY OF PETER E. NIELSEN (*author*); TOMMY MOORMAN (*illustration*)

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messenger RNA (mRNA), which is a strand of RNA with a copy of the base sequence of one strand in the DNA helix. A molecular machine known as a ribosome, itself made of RNA and protein, carries out the second stage, translation of the mRNA into the protein coded by the gene. Antisense agents interfere with translation by binding to the mRNA. These compounds are typically small, chemically modified RNA or DNA molecules, designed with the appropriate sequence to identify their mRNA target by Watson-Crick base-pairing. By binding to its mRNA, the agent may trigger enzymes to degrade the RNA or may simply interfere physically with the mRNA's functioning.

Cells make use of proteins called transcription factors that recognize specific sequences in double-stranded DNA to control gene expression at the transcription stage. These proteins can repress a gene by obstructing the RNA polymerase enzyme that would otherwise transcribe the DNA's sequence into mRNA, or they can activate a gene by helping the RNA polymerase to attach to the DNA and start transcription.

Although these proteins offer a model of molecules capable of "reading" the DNA sequence from the outside of the helix, in the 1990s it was not yet possible for biochemists to start with a sequence and design a new protein to recognize it. A gene-regulatory protein recognizes its DNA sequence by having the correct overall shape and chemical composition on its surface to bind with the sequence in the so-called major groove of the DNA, which provides access to the base pairs that run along the center of the double helix. But the structure of the protein's active surface depends on how its chain of amino acids folds up, a process that researchers cannot model with any accuracy.

Some progress has been made since then by taking the lead from gene-regulatory proteins that include zinc-finger domains, which are lengths of about 30 amino acids that fold around a zinc ion, forming a characteristic "finger" structure that can fit in the major groove with a few amino acids lined up with the DNA's bases. Researchers have developed artificial proteins with zinc fingers, but in general it is still difficult to program a sequence of amino acids to match even a relatively short DNA sequence.

A discovery dating back to 1957, only four years after the discovery of the DNA double helix, provides another approach. That year Gary Felsenfeld, Alexander Rich and David Davies, all then at the National Institute of Mental

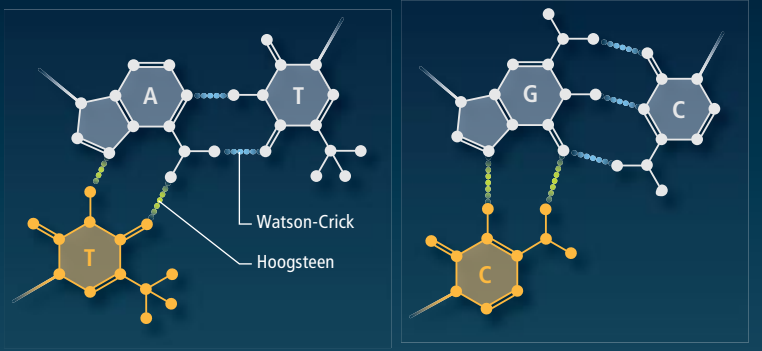
[HOW IT BINDS]

RECOGNIZING DNA

PNA binds to DNA and RNA both by Watson-Crick pairing of complementary bases (as occurs in ordinary double-stranded, or duplex, DNA) and by so-called Hoogsteen pairing, allowing a variety of structures to form and providing many ways for PNA to act as a drug in a cell.

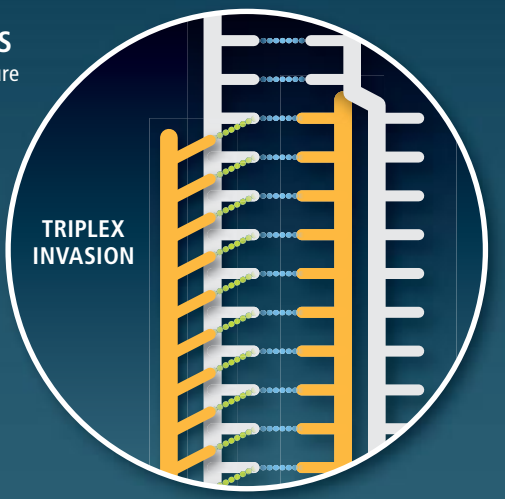
BASE-PAIRING

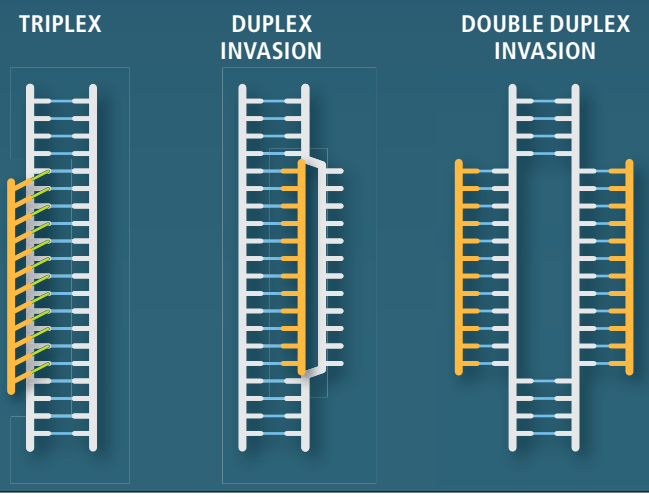
Watson-Crick pairing (*blue bonds*) links complementary bases A and T (*left*) and G and C (*right*). Hoogsteen pairing (*green bonds*) allows another T (*orange, left*) to join an A-T pair or a C (with an added hydrogen) to join a G-C pair.



PNA-DNA STRUCTURES

A particularly interesting structure that has a number of potentially useful biological effects in cells is the so-called triplex invasion (*right*), in which two PNA strands (*orange*) displace one strand of a duplex DNA molecule and form a triple-stranded, or triplex, structure with its partner. The other structures shown below include the basic PNA-DNA triplex, also depicted on page 65.





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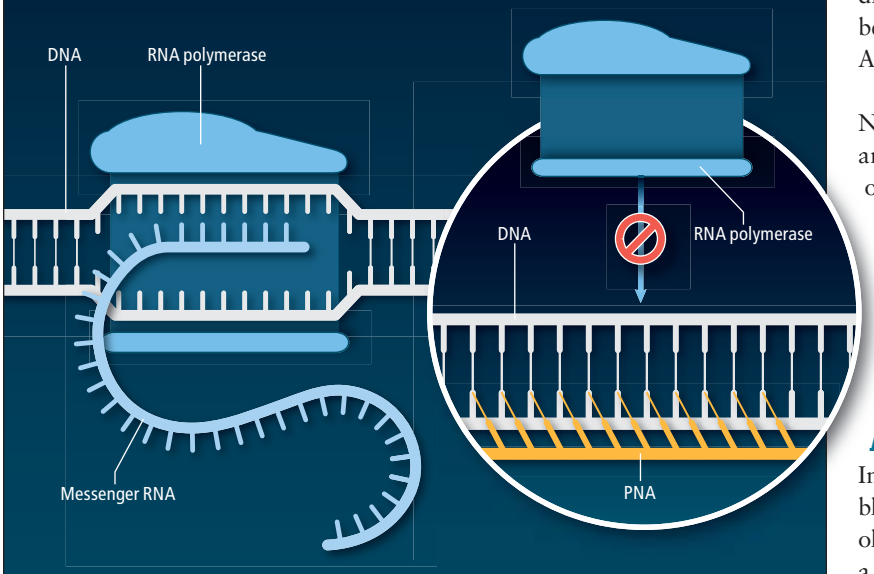
[MEDICAL EFFECTS]

GENE REGULATION BY PNA

PNA's ability to bind with double-stranded DNA as well as with RNA gives it several ways to modify the production of proteins encoded by specific genes.

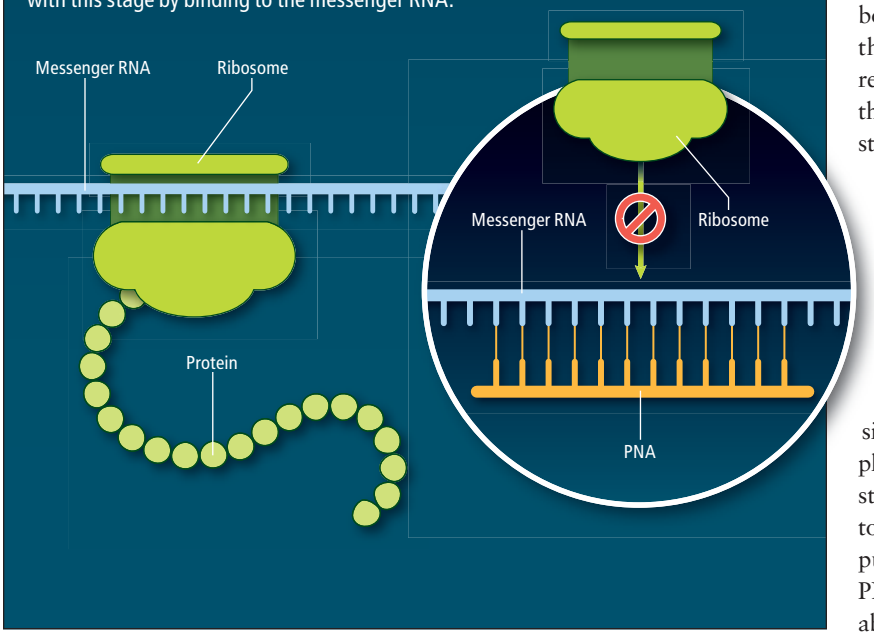
CONTROLLING TRANSCRIPTION

At the transcription stage, an enzyme (RNA polymerase) transcribes the information encoded by a DNA molecule into a messenger RNA molecule. PNA can block this process by binding to a part of the gene that is to be transcribed (*inset*). Alternatively, triplex invasion by PNA can promote transcription by exposing an appropriate stretch of single-stranded DNA to enzymes that initiate transcription (*not shown*).



BLOCKING TRANSLATION

In the second stage of protein production, a ribosome translates the sequence on the messenger RNA into a sequence of amino acids, forming the protein. PNA can interfere with this stage by binding to the messenger RNA.



Health, created triple helix structures in which a nucleic acid strand attaches itself in the major groove of a duplex nucleic acid molecule. The extra strand exploits a different kind of bonding of the base pairs T-A and C-G called Hoogsteen pairing, after Karst Hoogsteen [*see box on preceding page*]. Each position along the triplex thus has a triplet of bases in which a T binds to a T-A pair (T-A=T, where the "=" indicates the Hoogsteen pairing) or a C binds to a C-G unit (C-G=C). This structure, however, can form only when the extra strand is a homopyrimidine—made entirely of C and T (or U, in RNA)—because each Hoogsteen pair requires a G or an A on the strand of the double helix.

In 1987 the late Claude Hélène, then at the National Museum of Natural History in Paris, and Peter B. Dervan of the California Institute of Technology independently demonstrated that the triple helix structure could indeed be exploited to design oligonucleotides (DNA strands about 15 nucleotides long) that read the sequence in double-stranded DNA and bind their Hoogsteen complementary target.

A Surprise Invasion

Inspired by this digital readout of the DNA double helix by groove-binding, triple helix–forming oligonucleotides, my group set out to synthesize a molecule that could do the same trick with fewer limitations. In particular, we hoped to find molecules that would not be limited to recognizing sequences made entirely of G and A. We also wanted our molecule to be neutral. The backbone of nucleic acids contains phosphate groups that carry a negative charge in solution. The repulsion caused by these negative charges on all three backbones weakens the binding of the third strand to the triplex.

We therefore decided to base the design on amide chemistry, involving the same kind of bond as links amino acids in proteins. Well-established techniques using amide, or peptide, bonds allow convenient synthesis of highly stable, neutral molecules. The peptide nucleic acid molecule that we came up with has a peptidelike backbone made of a much simpler repeating unit than the sugar and phosphate of DNA and RNA. Each unit may have a standard nucleic acid base (T, A, C or G) linked to it or bases that have been modified for special purposes. The spacing between bases along a PNA is very close to that of DNA and RNA, enabling short PNA strands, or PNA oligomers, to

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form very stable duplex structures with DNA and RNA strands as well as with another PNA strand. The bases zip together with standard Watson-Crick bonding.

When we tried targeting duplex DNA with homopyrimidine PNA, to our surprise the PNA did not bind in the DNA's major groove as planned. Instead one PNA strand invaded the helix, displacing one of the DNA strands to form Watson-Crick bonds with its complement, and a second PNA strand formed Hoogsteen bonds to make a PNA-DNA=PNA triplex. The displaced length of DNA formed a single-stranded structure called a P-loop, alongside the triplex.

This triplex-invasion binding mode has several very interesting biological consequences, because the triplex has great stability and the P-loop affects central biological processes such as transcription, DNA replication and gene repair. For instance, the P-loop structure can initiate RNA transcription of the DNA. Furthermore, the single-stranded loop can be exploited in applications such as protocols to diagnose genetic disorders: the DNA in a sample must first be amplified (copied a large number of times), and the loop can serve as a specific attachment point for the copying process.

Other binding modes also occur, depending on the target DNA sequence and on how we modify the PNA's bases. Of these, double duplex invasion is particularly interesting. In this mode, we prepare two pseudocomplementary PNA oligomers—that is, their bases are modified enough to prevent formation of a PNA-PNA duplex but not enough to disrupt their individual binding to an ordinary complementary DNA strand. The PNAs thus invade double-stranded DNA and form two PNA-DNA duplexes. In contrast to triplex formation, which requires a long stretch of purines (A and G) in the target DNA, the double-duplex-invasion binding mode has less restrictive sequence requirements: with the present technology, the target sequence must contain at least 50 percent A-T base pairs. Even that constraint would be relaxed with discovery of suitable modified forms of the G and C bases.

PNA binds in these ways to complementary RNA or DNA molecules with even greater specificity and affinity than that exhibited by natural DNA. PNA oligomers with fluorescent groups attached are thus attractive as probes to detect specific genes in diagnostic tests. For instance, so-called fluorescence in situ hybridization analyses highlight the positions on chromosomes where specific sequences are present.

PROOFS OF CONCEPT

Many experiments have demonstrated how PNA oligomers can affect biological processes in ways that could be therapeutically useful.

Peter M. Glazer's group at Yale University showed in animal cells that PNA forming a triplex-invasion structure with DNA activated the repair of a gene carrying a mutation responsible for the human blood disease thalassemia. This process may eventually be exploited in therapy of diseases caused by single base mutations or small deletions in a gene.

David R. Corey of the University of Texas Southwestern Medical Center at Dallas and his co-workers showed in human breast cancer cells that PNA can block transcription by binding to a stretch of DNA that is separated into two strands just before the RNA polymerase enzyme starts transcribing the DNA into RNA. This process will provide insights into the role of specific genes in turning cells malignant.

Researchers have produced PNAs that block expression of essential genes in bacteria, inhibiting the bacteria's growth or even killing them. This discovery may lead to novel classes of antibiotics to combat the problem of bacterial resistance to existing drugs.

Prospects for Drugs

Many studies, in cell cultures as well as solutions in vitro, have demonstrated proof of concept for using PNA oligomers to suppress or activate the transcription, replication or repair of specific genes by binding to DNA in various ways. Researchers have also reported numerous experiments showing that PNA oligomers can function somewhat in the manner of antisense RNA interference, inhibiting gene expression at the translation stage, both in cell cultures and in a few studies with mice. PNA achieves these effects by physically blocking key processes involving RNA. In contrast, DNA or RNA oligomers used for RNA interference are assisted by enzymes in cells that break down the RNA-DNA or RNA-RNA duplexes that are formed. The RNA-PNA structure is unlikely to receive this kind of assistance because the enzymes cannot recognize such a foreign structure, although so far researchers have studied the question only for one of the relevant enzymes. Yet the alien nature of PNA oligomers also makes them exquisitely stable in biological environs—enzymes that break down other peptides do not recognize them, so PNAs have more time to encounter matching RNA and disable it.

In some cases, blocking an RNA process can restore a healthy protein. Matthew Wood of the University of Oxford and his co-workers demonstrated in 2007 that PNA can exploit this effect. When they injected PNA into mice with muscular dystrophy, the injected muscles showed increased levels of the protein dystrophin, whose absence causes muscular dystrophy. The PNA prevented a bad segment of the dystrophin gene from being translated from RNA to protein, thus eliminating a debilitating mutation present in that segment while leaving intact enough of the dystrophin to function.

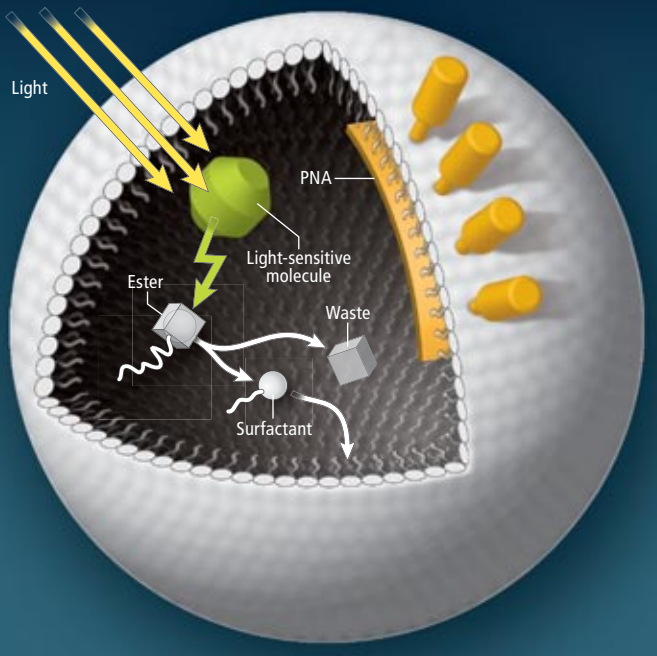
PNA oligomers and conventional nucleic acids share a common problem of poor bioavailability because they are large and predominantly hydrophilic (water-loving) molecules, making it difficult for them to enter cells, whose walls are made of hydrophobic lipid membrane. Despite the great stability of PNAs, they do not remain in an animal for long, being quickly excreted in urine thanks to their hydrophilicity. For instance, half of the PNA in a mouse is gone in less than half an hour. Thus, the advent of PNA-based drugs awaits the development of suitable chemical modifications or pharmaceutical formulations (that is, mixtures with other substances) to improve PNA bioavailability. Indeed, the

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[ALIEN GENES]

ARTIFICIAL LIFE

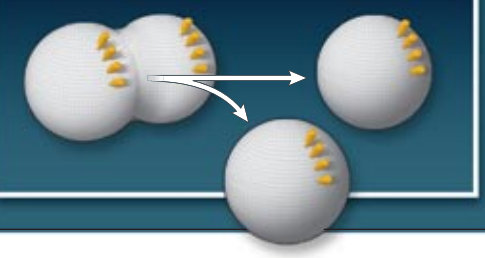
Researchers striving to construct new life-forms out of combinations of nonliving chemicals are considering PNA as the genetic (information-carrying) component of their designs because it is simpler and more stable than DNA or RNA. In the proposal shown below, PNA is embedded in the surface of a container that self-assembles out of surfactant molecules. Light-sensitive molecules in the cell power the generation of more surfactant molecules from precursor esters. If the PNA replicates (*top*), the expanding protocell may divide into two similar copies (*bottom*). By self-organizing, metabolizing (exploiting an energy source) and self-replicating, the protocell exhibits some of the hallmarks of life.



The PNA replicates when short, complementary PNA fragments attach to it and it migrates to the protocell's lipid interior, where the fragments join to form a second PNA strand.



When the protocell grows large enough, it becomes unstable and divides in two.



main focus of research into genetic medicines in general is work on overcoming the problem of delivery to cells in the body. Researchers believe that hurdle is the last obstacle holding back medical breakthroughs in this field.

Artificial Life

By bridging the realms of nucleic acids and proteins, PNA might be able to serve both as a store of information, like DNA, and as the catalytic machinery of an artificial cell, like the many protein-based enzymes in natural cells. It is that potential dual ability, along with PNA's other properties, that has attracted the interest of scientists seeking to create artificial life.

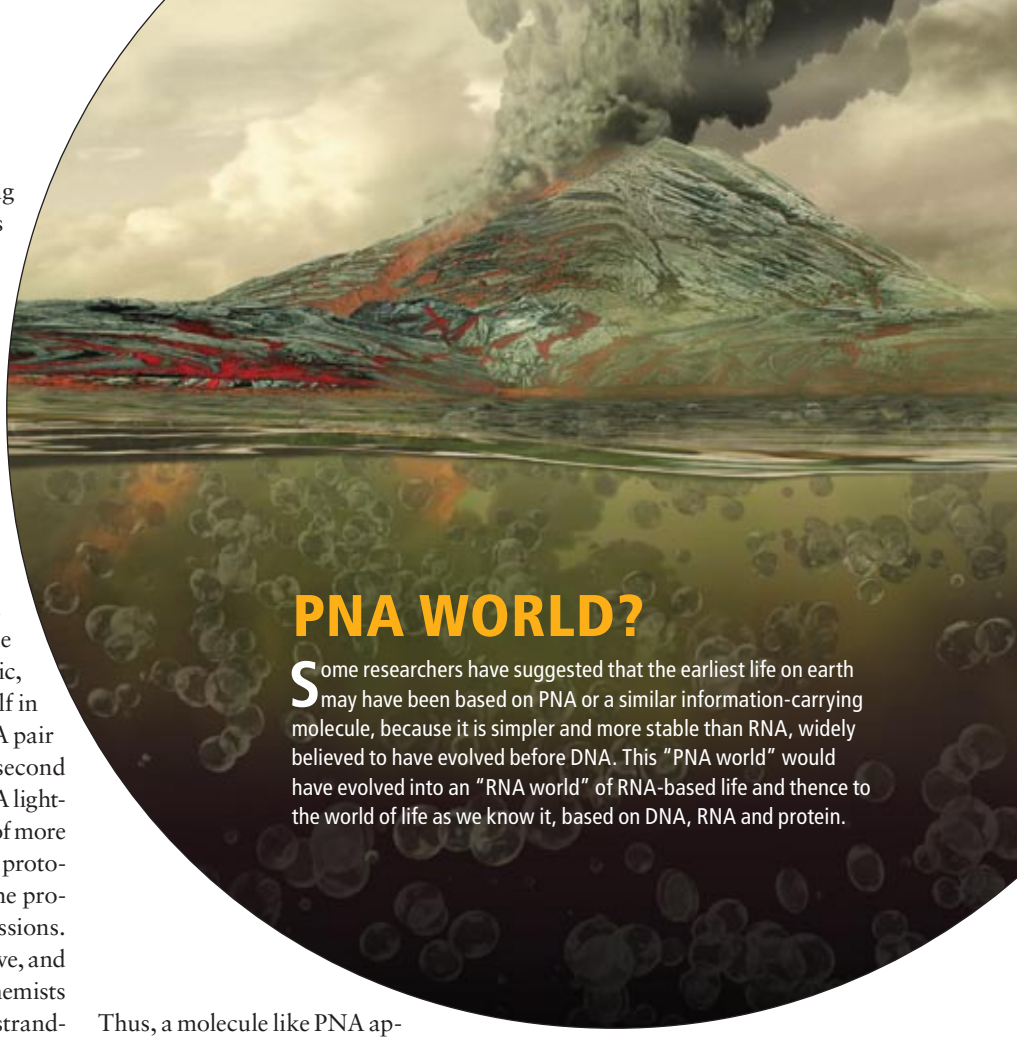
In many respects, however, RNA is ahead of PNA in this game. Natural and synthesized examples of catalytic RNA abound. Catalytic PNA molecules, in contrast, remain to be discovered. Yet just like proteins and RNA, PNA oligomers do fold up into the kinds of shapes (so-called secondary and tertiary structures) that are the key to performing catalysis, so I believe it is just a matter of time before a catalytic variation on the PNA theme is developed.

The most advanced approaches to creating life from the bottom up, by assembling collections of molecules, seek to identify self-replicating RNA molecules that catalyze their own synthesis. In principle, the RNA molecules in these schemes could be substituted with PNA or a very similar synthetic molecule. Autocatalytic replication systems using short oligonucleotides have been discovered, as have self-replicating short peptides. Thus, it should be possible to develop analogous self-replicating PNA systems. A self-replicating system based on PNA would have the advantage of chemically robust peptide bonds, along with the versatility and specificity of base-sequence recognition.

Yet a genetic replication system is only one component of life, albeit a central one. The essence of life is a network of chemical reactions functioning in a state that is relatively stable yet not in equilibrium and that is open to both inputs and outputs [see "A Simpler Origin for Life," by Robert Shapiro; SCIENTIFIC AMERICAN, June 2007]. A major challenge will there-

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PNA WORLD?

Some researchers have suggested that the earliest life on earth may have been based on PNA or a similar information-carrying molecule, because it is simpler and more stable than RNA, widely believed to have evolved before DNA. This "PNA world" would have evolved into an "RNA world" of RNA-based life and thence to the world of life as we know it, based on DNA, RNA and protein.

fore be to incorporate the self-replicating molecule in a larger system that carries out other catalytic activity and has a metabolic cycle and to integrate the system with a physical compartment such as a lipid vesicle, forming what some researchers call a "protocell."

Steen Rasmussen of Los Alamos National Laboratory and Liaohai Chen of Argonne National Laboratory have suggested a primitive protocell design based on PNA [*see box on opposite page*]. The protocell container self-assembles out of surfactant molecules—lipid chains with hydrophilic, or water loving, heads. The PNA's backbone is modified to be lipophilic, or oil-loving, so that the PNA embeds itself in the protocell's surface. Short pieces of PNA pair up with the protocell's PNA to form a second strand with the complementary sequence. A light-sensitive molecule powers the production of more surfactant molecules, which increases the protocell's size. When it grows large enough, the protocell becomes unstable and naturally fissions. This proposal is, however, highly speculative, and it still suffers from a basic problem that chemists have yet to solve—the stability of double-stranded PNA greatly inhibits its separation into two daughter strands. A long, tortuous road remains before researchers develop robust artificial cells.

Origin of Life?

A major goal of these efforts to create life de novo in the laboratory is to better understand how life may have started on earth. Considering the detailed microbiology of contemporary life-forms, it seems very clear that RNA is probably more primordial and central to life than DNA and proteins. This one molecule can carry both the genotype (the genetic sequence information) of an organism and the phenotype (catalytic functions). For this reason as well as other evidence, many scientists now accept the idea that our DNA/RNA/protein world was preceded by an RNA world [see "The Origin of Life on the Earth," by Leslie E. Orgel; Scientific American, October 1994].

Yet it is very unclear how primitive prebiotic conditions could have produced RNA molecules, in particular the sugar ribose in the RNA backbone. Further, even if RNA molecules were produced, RNA's very poor chemical stability hardly would have allowed the molecules to survive unprotected long enough to play a central role in the initial chemical evolution of life. Thus, a molecule like PNA appears very attractive as a candidate for a pre-RNA world: it is extremely stable and chemically simple, and it carries sequence information.

In 2000 Stanley L. Miller, famous for his seminal experiments more than 50 years ago showing that amino acids can form under conditions believed to simulate those on the primitive earth, identified precursors of PNA in similar experiments. Researchers have also shown that sequence information in a PNA oligomer can be transferred by "chemical copying" to another PNA oligomer or to an RNA molecule—processes needed for a PNA world and then a following transitional PNA/RNA world. Admittedly, it is a long leap from these scanty observations to building a strong case for a pre-RNA world based on PNA or some very similar molecule, and for the hypothesis to have any legs at all, scientists must uncover PNA molecules possessing catalytic activity.

Much remains to be learned about PNA 15 years after its discovery: Are catalytic PNA molecules possible? What is a good system for delivering therapeutic PNA into cells? Can a totally alien, PNA-based life-form be created in the lab? I am confident these questions and many others will be well answered over the next 15 years. ■

MORE TO EXPLORE

Sequence-Selective Recognition of DNA by Strand Displacement with a Thymine-Substituted Polyamide. Peter E. Nielsen, Michael Egholm, Rolf H. Berg and Ole Buchardt in *Science,* Vol. 254, pages 1497–1500; December 6, 1991.

Template Switching between PNA and RNA Oligonucleotides. Christof Böhler, Peter E. Nielsen and Leslie E. Orgel in *Nature,* Vol. 376, pages 578–581; August 17, 1995.

Peptide Nucleic Acid: A Molecule with Two Identities. Peter E. Nielsen in *Accounts of Chemical Research,* Vol. 32, No. 7, pages 624–630; July 1999.

Synthesizing Life. Jack W. Szostak, David P. Bartel and P. Luigi Luisi in *Nature,* Vol. 409, pages 387–390; January 18, 2001.

Prebiotic Chemistry and the Origin of the RNA World. Leslie E. Orgel in *Critical Reviews in Biochemistry and Molecular Biology,* Vol. 39, No. 2, pages 99–123; March/April 2004.

JEAN-FRANCOIS PODEVIN

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Magic and the Brain

Magicians have been testing and exploiting the limits of cognition and attention for hundreds of years. Neuroscientists are just beginning to catch up



By Susana Martinez-Conde and Stephen L. Macknik

KEY CONCEPTS

- Magic tricks often work by covert misdirection, drawing the spectator's attention away from the secret "method" that makes a trick work.
- Neuroscientists are scrutinizing magic tricks to learn how they can be put to work in experimental studies that probe aspects of consciousness not necessarily grounded in current sensory reality.
- Brain imaging shows that some regions are particularly active during certain kinds of magic tricks.

—The Editors

The spotlight shines on the magician's assistant. The woman in the tiny white dress is a luminous beacon of beauty radiating from the stage to the audience. The Great Tomsoni announces he will change her dress from white to red. On the edge of their seats, the spectators strain to focus on the woman, burning her image deep into their retinas. Tomsoni claps his hands, and the spotlight dims ever so briefly before reflaring in a blaze of red. The woman is awash in a flood of redness.

Whoa, just a moment there! Switching color with the spotlight is not exactly what the audience had in mind. The magician stands at the side of the stage, looking pleased at his little joke. Yes, he admits, it was a cheap trick; his favorite kind, he explains devilishly. But you have to agree, he did turn her dress red—along with the rest of her. Please, indulge him and direct your attention once more to his beautiful assistant as he switches the lights back on for the next trick. He claps his hands, and the lights dim again; then the stage explodes in a supernova of whiteness. But wait! Her dress really has turned red. The Great Tomsoni has done it again!

The trick and its explanation by John Thompson (aka the Great Tomsoni) reveal a deep intuitive understanding of the neural processes taking place in the spectators' brains—the kind of understanding that we neuroscientists can appropriate for our own scientific benefit. Here's how the trick works. As Thompson introduces his assistant, her skintight white dress wordlessly lures the spectators into assuming that nothing—certainly not another dress—could possibly be hiding under the white one. That reasonable assumption, of course, is wrong. The attractive woman in her tight dress also helps to focus people's attention right where Thompson wants it—on the woman's body. The more they stare at her, the less they notice the hidden devices in the floor, and the better adapted their retinal neurons become to the brightness of the light and the color they perceive.

All during Thompson's patter after his little "joke," each spectator's visual system is undergoing a brain process called neural adaptation. The responsiveness of a neural system to a constant stimulus (as measured by the firing rate of the relevant neurons) decreases with time. It is as if neurons actively ignore a constant stimulus to save their strength for signaling that a stimulus is changing. When the constant stimulus is turned off, the adapted neurons fire a "rebound" response known as an afterdischarge.

In this case, the adapting stimulus is the red-lit dress, and Thompson knows that the spectators' retinal neurons will rebound for a fraction of a second after the lights are dimmed. The audience will continue to see a red afterimage in the shape of the woman. During that split second, a trap door in the stage opens briefly, and

JEAN-FRANCOIS PODEVIN (*hat and wand*); MISHA GRAVENOR (*Penn & Teller*)

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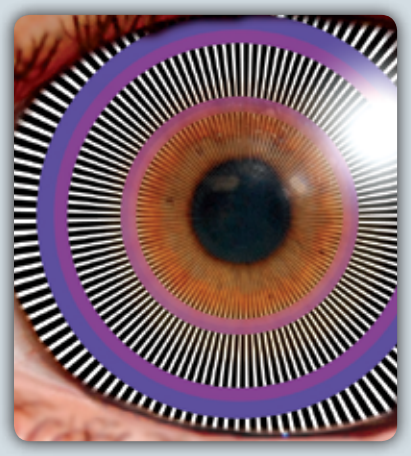
MAGICIANS PENN & TELLER perform an updated version of the classic "saw the lady in half" trick that still creates an unforgettable illusion (Penn is operating the saw; Teller is his all-too-willing victim). Neuroscientists are adapting the methods of magic in several kinds of experiments, among them the study of how the brain responds to perceptions that seem to violate all prior experience with reality.

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[VISUAL ILLUSIONS]

FOOLING MIND OR EYE?

An illusion based on the painting *Enigma*, by French artist Isia Léviant, often induces a false sense of flowing movement in the concentric rings (stare at the center dot in the picture). But does the illusion originate in the mind or in the eye? The evidence was conflicting until the authors and their colleagues showed in October that the illusory motion is driven by microsaccades—small, involuntary eye movements that occur during visual fixation. Knowing the roles of eye and mind in magic is essential before the illusions of magic can be used as experimental tools in neuroscience.



COGNITIVE ILLUSIONS

Neuroscientists are studying the ways magicians exploit mental lapses, among them:

- **CHANGE BLINDNESS**
 A viewer misses changes made to a scene during a brief interruption.

 EXAMPLE: Color of furniture is changed between scenes of a play.

- **INATTENTIONAL BLINDNESS**
 A spectator does not perceive items that are plainly in view.

 EXAMPLE: A person in a gorilla suit wanders into a scene and goes unnoticed.

- **CHOICE BLINDNESS**
 A spectator explains the reasons for a choice, even though the choice was not made.

 EXAMPLE: A man does not notice when a photograph he selected is secretly swapped for another and explains his "preference" for the latter [*see box at bottom of page 77*].

- **ILLUSORY CORRELATION**
 One unrelated event appears to cause another.

 EXAMPLE: A magician waves a wand, and a rabbit appears.

the white dress, held only lightly in place with Velcro and attached to invisible cables leading under the stage, is ripped from her body. Then the lights come back up.

Two other factors help to make the trick work. First, the lighting is so bright just before the dress comes off that when it dims, the spectators cannot see the rapid motions of the cables and the white dress as they disappear underneath the stage. The same temporary blindness can overtake you when you walk from a sunny street into a dimly lit shop. Second, Thompson performs the real trick only after the audience thinks it is already over. That gains him an important cognitive advantage—the spectators are not looking for a trick at the critical moment, and so they slightly relax their scrutiny.

The New Science of Neuromagic

Thompson's trick nicely illustrates the essence of stage magic. Magicians are, first and foremost, artists of attention and awareness. They manipulate the focus and intensity of human attention, controlling, at any given instant, what we are aware of and what we are not. They do so in part by employing bewildering combinations of visual illusions (such as afterimages), optical illusions (smoke and mirrors), special effects (explosions, fake gunshots, precisely timed lighting controls), sleight of hand, secret devices and mechanical artifacts ("gimmicks").

But the most versatile instrument in their bag of tricks may be the ability to create cognitive illusions. Like visual illusions, cognitive illusions mask the perception of physical reality. Yet unlike visual illusions, cognitive illusions are not sensory in nature. Rather they involve high-level functions such as attention, memory and causal inference. With all those tools at their disposal, well-practiced magicians make it virtually impossible to follow the physics of what is actually happening—leaving the impression that the only explanation for the events is magic.

Neuroscientists are just beginning to catch up with the magician's facility in manipulating attention and cognition. Of course the aims of neuroscience are different from those of magic; the neuroscientist seeks to understand the brain and neuron underpinnings of cognitive functions, whereas the magician wants mainly to exploit cognitive weaknesses. Yet the techniques developed by magicians over centuries of stage magic could also be subtle and powerful probes in the hands of neuroscientists, supplementing and perhaps expanding the instruments already in experimental use.

Neuroscience is becoming familiar with the methods of magic by subjecting magic itself to scientific study—in some cases showing for the first time how some of its methods work in the brain. Many studies of magic conducted so far confirm what is known about cognition and attention from earlier work in experimental psychology. A cynic might dismiss such efforts: Why do yet another study that simply confirms what is already well known? But such criticism misses the importance and purpose of the studies. By investigating the techniques of magic, neuroscientists can familiarize themselves with methods that they can adapt to their own purposes. Indeed, we believe that cognitive neuroscience could have advanced faster had investigators probed magicians' intuitions earlier. Even today magicians may have a few tricks up their sleeves that neuroscientists have not yet adopted.

By applying the tools of magic, neuroscientists can hope to learn how to design more robust experiments and to create more effective cognitive and visual illusions for exploring the neural bases of attention and awareness. Such techniques could not only make experimental studies of cognition possible with clever and highly attentive subjects; they could also lead to diagnostic and treatment methods for patients suffering from specific cognitive deficits—such as attention deficits resulting from brain trauma, ADHD (attention-deficit hyperactivity disorder), Alzheimer's disease, and the like. The methods of magic might also be put to work in "tricking" patients to focus on the most important parts of their therapy, while suppressing distractions that cause confusion and disorientation.

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Magicians use the general term "misdirection" to refer to the practice of diverting the spectator's attention away from a secret action. In the lingo of magic, misdirection draws the audience's attention toward the "effect" and away from the "method," the secret behind the effect. Borrowing some terms from cognitive psychology, we have classified misdirection as "overt" and "covert." The misdirection is overt if the magician redirects the spectator's gaze away from the method—perhaps simply by asking the audience to look at a particular object. When the Great Tomsoni introduces his lovely assistant, for instance, he ensures that all eyes are on her.

"Covert" misdirection, in contrast, is a subtler technique; there, too, the magician draws the spectator's attentional spotlight—or focus of suspicion—away from the method, but without necessarily redirecting the spectator's gaze. Under the influence of covert misdirection, spectators may be looking directly at the method behind the trick yet be entirely unaware of it.

Cognitive neuroscience already recognizes at least two kinds of covert misdirection. In what is called change blindness, people fail to notice that something about a scene is different from the way it was before. The change may be expected or unexpected, but the key feature is that observers do not notice it by looking at the scene at any one instant in time. Instead the observer must compare the postchange state with the prechange state.

Many studies have shown that changes need not be subtle to cause change blindness. Even dramatic alterations in a visual scene go unnoticed if they take place during a transient interruption such as a blink, a saccadic eye movement (in which the eye quickly darts from one point to another) or a flicker of the scene. The "color-changing card trick" video by psychologist and magician Richard Wiseman of the University of Hertfordshire in England is a dramatic example of the phenomenon (the video is available online at www.youtube.com/watch?v=voAntzB7EwE). In Wiseman's demonstration—which you must see to appreciate—viewers fail to notice shifts in color that take place off camera. It is worth noting that despite its name, the color-changing card trick video does not use magic to make its point.

Inattentional blindness differs from change blindness in that there is no need to compare the current scene with a scene from memory. Instead people fail to notice an unexpected object that is fully visible directly in front of them. Psychologist Daniel J. Simons invented a classic example of the genre. Simons and psychologist Christopher F. Chabris, both then at Harvard University, asked observers to count how many times a "team" of three basketball players pass a ball to each other, while ignoring the passes made by three other players. While they concentrated on counting, half of the observers failed to notice

[THE AUTHORS]

Susana Martinez-Conde and Stephen L. Macknik are at the Barrow Neurological Institute in Phoenix, where Martinez-Conde is director of the Laboratory of Visual Neuroscience and Macknik is director of the Laboratory of Behavioral Neurophysiology. Their article "Windows on the Mind" appeared in the August 2007 issue of *Scientific American*.

The authors thank their magician collaborators for sharing many insights: Mac King, James Randi (aka the Amaz!ng Randi), Apollo Robbins, Teller (from Penn & Teller) and John Thompson (aka the Great Tomsoni). They are also grateful to the Association for the Scientific Study of Consciousness and the Mind Science Foundation.

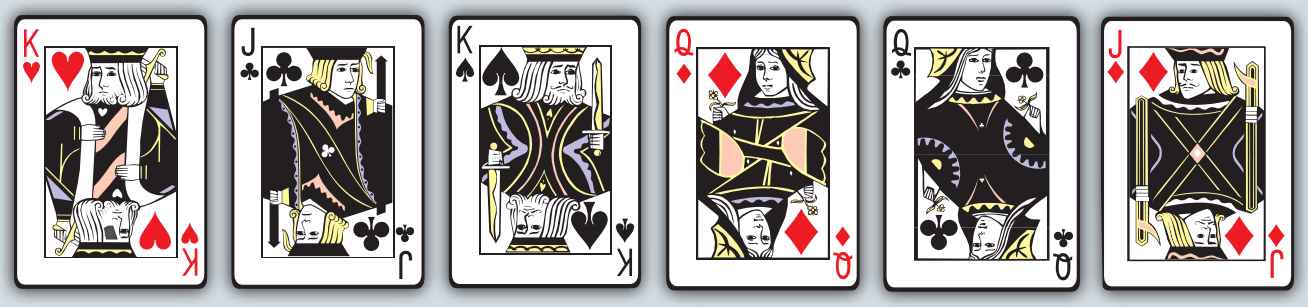




[CHANGE BLINDNESS]

CAN YOU KEEP US FROM READING YOUR MIND?

Can you explain the astounding results of the following mind-reading experiment by Clifford Pickover, a prolific author of popular books about science and mathematics? The editors of *Scientific American* have prepared a simulated Pickover test that you can take here, or you can try the even more puzzling online version at http://sprott.physics.wisc.edu/pickover/esp.html. By using his system of ESP, we think we can predict the correct outcome of your choice with 98 percent accuracy. To begin, pick one of the six cards below and remember it.



Say its name aloud several times so you won't forget it. Once you're sure you'll remember it, circle one of the eyes in the row below. Then turn to page 79.



JEFF NOBLE (*Martinez-Conde and Macknik*)

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[INATTENTIONAL BLINDNESS]

HOW TO PULL COINS OUT OF THIN AIR

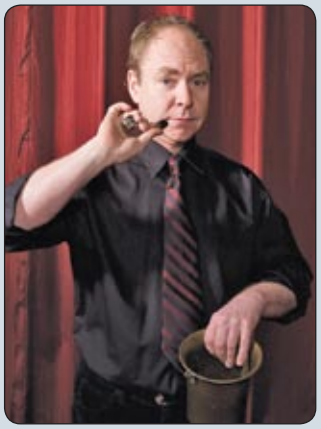
The magician Teller relies on misdirection and sleight of hand to create an illusion called the Miser's Dream. He begins by secretly palming six coins in each hand, then apparently produces the coins out of anything he can reach—his own hair, the clothing of his spectators, empty space—and tosses them into



Having demonstrated his bucket is empty, Teller starts producing coins in his right hand.



By directing his gaze to his right hand, he diverts his audience's attention from his left hand. But it is the left hand, the one holding the bucket, from which he is dropping hidden coins.



In fact, he is repeatedly producing the same coin in his right hand.



Just as the audience begins to suspect that Teller is simply dropping palmed coins from his right hand, he drops five of the six coins from his right hand all at once. That astounds the audience, because he could not have palmed 11 coins in his right hand.



MISHA GRAVENOR (*Teller*)

that a person in a gorilla suit walks across the scene (the gorilla even stops briefly at the center of the scene and beats its chest!). No abrupt interruption or distraction was necessary to create this effect; the counting task was so absorbing that many observers who were looking directly at the gorilla nonetheless missed it.

Tricking the Eye or Tricking the Brain?

Magicians consider the covert form of misdirection more elegant than the overt form. But neuroscientists want to know what kinds of neural and brain mechanisms enable a trick to work. If the artistry of magic is to be adapted by neuroscience, neuroscientists must understand what kinds of cognitive processes that artistry is tapping into.

Perhaps the first study to correlate the perception of magic with a physiological measurement was published in 2005 by psychologists Gustav Kuhn of Durham University in England and Benjamin W. Tatler of the University of Dundee in Scotland. The two investigators measured the eye movements of observers while Kuhn, who is also a magician, made a cigarette "disappear" by dropping it below a table. One of their goals was to determine whether observers missed the trick because they were not looking in the right place at the right time or because they did not attend to it, no matter which direction they were looking. The results were clear: it made no difference where they were looking.

A similar study of another magic trick, the "vanishing-ball illusion," provides further evidence that the magician is manipulating the spectators' attention at a high cognitive level; the direction of their gaze is not critical to the effect. In the vanishing-ball illusion the magician begins by tossing a ball straight up and catching it several times without incident. Then, on the final toss, he only pretends to throw the ball. His head and eyes follow the upward trajectory of an imaginary ball, but instead of tossing the ball, he secretly palms it. What most spectators perceive, however, is that the (unthrown) ball ascends—and then vanishes in midair.

The year after his study with Tatler, Kuhn and neurobiologist Michael F. Land of the University of Sussex in England discovered that the spectators' gaze did not point to where they themselves claimed to have seen the ball vanish. The finding suggested the illusion did not fool the brain systems responsible for the spectators' eye motions. Instead, Kuhn and Land concluded, the magician's head and eye movements were critical to the illusion, because they covertly redirected the spectators' attentional focus (rather than their gaze) to the predicted position of the ball. The neurons that responded to the implied motion of the ball suggested by the magician's head and eye movements are found in the same

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a metal bucket with a loud clank. The deception depends in part on social cues such as head position and gaze direction.



Teller produces the final palmed coin from his right hand, then turns his hand to show that his palm is, in fact, empty.



Spectacularly, Teller throws the 11 coins from the bucket as he continues to hold the final coin in his right hand.

visual areas of the brain as neurons that are sensitive to real motion. If implied and real motion activate similar neural circuits, perhaps it is no wonder that the illusion seems so realistic.

Kuhn and Land hypothesized that the vanishing ball may be an example of "representational momentum." The final position of a moving object that disappears is perceived to be farther along its path than its actual final position—as if the predicted position was extrapolated from the motion that had just gone before.

More Tools of the Trickery Trade

Spectators often try to reconstruct magic tricks to understand what happened during the show—after all, the more the observer tries (and fails) to understand the trick, the more it seems as if it is "magic." For their part, magicians often dare their audiences to discover their methods, say, by "proving" that a hat is empty or an assistant's dress is too tight to conceal a second dress underneath. Virtually everything done is done to make the reconstruction as hard as possible, via misdirection.

But change blindness and inattentional blindness are not the only kinds of cognitive illusions magicians can pull out of a hat. Suppose a magician needs to raise a hand to execute a trick. Teller, half of the renowned stage magic act known as Penn & Teller, explains that if he raises his hand for no apparent reason, he is more likely to draw suspicion than if he makes a hand gesture—such as adjusting his glasses or scratching his head—that seems natural or spontaneous. To magicians, such gestures are known as "informing the motion."

Unspoken assumptions and implied information are also important to both the perception of a trick and its subsequent reconstruction. Magician James Randi ("the Amaz!ng Randi") notes that spectators are more easily lulled into accepting suggestions and unspoken information than direct assertions. Hence, in the reconstruction the spectator may remember implied suggestions as if they were direct proof.

Psychologists Petter Johansson and Lars Hall, both at Lund University in Sweden, and their colleagues have applied this and other magic techniques in developing a completely novel way of addressing neuroscientific questions. They presented picture pairs of female faces to naive experimental subjects and asked the subjects to choose which face in each pair they found more attractive. On some trials the sub-

VISUAL ILLUSIONS IN MAGIC

Not all magic is cognitive. Exploiting well-known properties of the visual system can also lead to unusual effects, among them:

■ SPOON BENDING

A magician shakes a spoon, making its neck appear flexible.

WHY IT WORKS:

Neurons in the visual cortex sensitive to both motion and line endings respond differently to oscillations than other visual neurons do. The result is an apparent discrepancy between the ends of a stimulus and its center; a solid object seems to flex in the middle.

■ THE RETENTION OF VISION VANISH

The magician removes an object from the visual field, but it still appears visible for a short time.

WHY IT WORKS:

Neural afterdischarge produces afterimages for about 100 milliseconds after a stimulus ceases.

■ JERRY ANDRUS'S TRIZONAL SPACE WARP

Spectators stare at a spinning disk with three zones of expanding and contracting motion. When they then look at a stationary object, it, too, seems to expand and contract.

WHY IT WORKS:

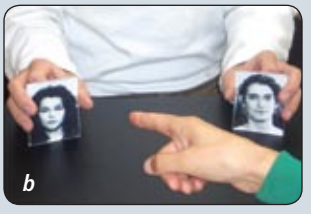
Neurons adapt differently to the motions in the three zones of the visual field.

[CHOICE BLINDNESS]

INDUCING FALSE NARRATIVES

In an experiment, subjects were shown pairs of photographs (*a*) and asked to choose the more attractive image (*b*). After each choice, the experimenters turned the photographs face down (*c*) and used sleight of hand to swap some of the chosen images for the rejected ones. The "choice" was then once again turned face up, and the subjects were asked to explain their preference. Even when the choice shown was actually the rejected image (*d*), many subjects constructed an "explanation" for the choice. The urge for people to fit what they falsely think are their own choices into an internally consistent narrative can thus often supplant the memory of their actual selections.









FROM *NATURE REVIEWS NEUROSCIENCE*, JULY 30, 2008, REPRINTED BY PERMISSION OF MACMILLAN PUBLISHERS LTD (*a–d*)

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jects were also asked to describe the reasons for their choice. Unknown to the subjects, the investigators occasionally used a sleight-of-hand technique, learned from a professional magician named Peter Rosengren, to switch one face for the other—*after* the subjects made their choice. Thus, for the pairs that were secretly manipulated, the result of the subject's choice became the opposite of his or her initial intention.

Intriguingly, the subjects noticed the switch in only 26 percent of all the manipulated pairs. But even more surprising, when the subjects were asked to state the reasons for their choice in a manipulated trial, they confabulated to justify the outcome—an outcome that was the opposite of their actual choice! Johansson and his colleagues call the phenomenon "choice blindness." By tacitly but strongly suggesting the subjects had already made a choice, the investigators were able to study how people justify their choices—even choices they do not actually make.

The Pickpocket Who Picks Your Brain

Misdirection techniques might also be developed out of the skills of the pickpocket. Such thieves, who often ply their trade in dense public spaces, rely heavily on socially based misdirection—gaze contact, body contact and invasion of the personal space of the victim, or "mark." Pickpockets may also move their hands in distinct ways, depending on their present purpose. They may sweep out a curved path if they want to attract the mark's attention to the entire path of motion, or they may trace a fast, linear path if they want to reduce attention to the path and quickly shift the mark's attention to the final position. The neuroscientific underpinnings of these maneuvers are unknown, but our research collaborator Apollo Robbins, a professional pickpocket, has emphasized that the two kinds of motions are essential to effectively misdirecting the mark. We have proposed several possible, testable explanations.

One proposal is that curved and straight hand motions activate two distinct control systems in the brain for moving the eyes. The "pursuit" system controls the eyes when they follow smoothly moving objects, whereas the "saccadic" system controls movements in which the eyes jump from one visual target to the next. So we have hypothesized that the pickpocket's curved hand motions may trigger eye control by the mark's pursuit system, whereas fast, straight motions may cause the saccadic system to take the lead. Then if the mark's pursuit system locks onto the curved trajectory of the pickpocket's hand, the center of the mark's vision may be drawn away from the location of a hidden theft. And if fast, straight motions engage the mark's saccadic system, the pickpocket gains the advantage that the mark's vision is suppressed while the eye darts from point to point. (The phenomenon is well known in the vision sciences as saccadic suppression.)

Another possible explanation for the distinct hand motions is that curved motions may be perceptually more salient than linear ones and hence attract stronger attention. If so, only the attentional system of the brain—not any control system for eye motions—may be affected by the pickpocket's manual misdirection. Our earlier studies have shown that the curves and corners of objects are more salient and generate stronger brain activity than straight edges. The reason is probably that sharp curves and corners are less predictable and redundant (and therefore more novel and informative) than straight edges. By the same token, curved trajectories may be less redundant, and therefore more salient, than straight ones.

[THE PICKPOCKET'S ART]

MULTISENSORY MISDIRECTION

Apollo Robbins (*below right*), who bills himself as a professional thief, demonstrates that misleading the "mark" to look in one direction keeps the mark from attending to his valuables. Robbins relies on the manipulation of touch and the mark's personal space as well as on misdirecting vision. An astonishing video of Robbins surreptitiously removing another man's wristwatch is available at **http://tinyurl.com/6lhxy8**



COURTESY OF APOLLO ROBBINS

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[ILLUSORY CORRELATION]

HOW THE BRAIN DEALS WITH THE "IMPOSSIBLE"

Videos of magic tricks that seemed to portray impossible causal relations, such as making a ball vanish (*top row of photographs*), were shown to experimental subjects, while functional magnetic resonance images were made of the subjects' brains. A control group saw highly similar videos, except that no magic trick was performed (*bottom row*). The areas of the brain highlighted in color (*below right*) show where additional neural activity took place when the subjects viewed the magic videos instead of the control videos.



Controlling Awareness in the Wired Brain

The possibilities of using magic as a source of cognitive illusion to help isolate the neural circuits responsible for specific cognitive functions seem endless. Neuroscientists recently borrowed a technique from magic that made volunteer subjects incorrectly link two events as cause and effect while images of the subjects' brains were recorded. When event A precedes event B, we often conclude, rightly or wrongly, that A causes B. The skilled magician takes advantage of that predisposition by making sure that event A (say, pouring water on a ball) always precedes event B (the ball disappearing). In fact, A does not cause B, but its prior appearance helps the magician make it seem so. Cognitive psychologists call this kind of effect illusory correlation.

In an unpublished study in 2006 Kuhn and cognitive neuroscientists Ben A. Parris and Tim L. Hodgson, both then at the University of Exeter in England, showed videos of magic tricks that involved apparent violations of cause and effect to subjects undergoing functional magnetic resonance imaging. The subjects' brain images were compared with those of a control group: people who watched videos showing no apparent causal violations. The investigators found greater activation in the anterior cingulate cortex among the subjects who were watching magic tricks than among the controls. The finding suggests that this brain area may be important for interpreting causal relationships.

The work of Kuhn and his colleagues only begins to suggest the power of the techniques of magic for manipulating attention and awareness while studying the physiology of the brain. If neuroscientists learn to use the methods of magic with the same skill as professional magicians, they, too, should be able to control awareness precisely and in real time. If they correlate the content of that awareness with the functioning of neurons, they will have the means to explore some of the mysteries of consciousness itself. ■

We Read Your Mind

We have removed your card!



Did we guess the card you picked on page 75? If so, does Pickover's ESP system explain our correct answer, or is there a simpler explanation? Read no further until you want to know the answer.

Give up? Look once more at the six cards on page 75, then compare them with the five cards pictured here. Notice any differences? If the act of circling an eye distracted you and you fell for the trick (most people do), you are a victim of what psychologists call change blindness. A change—even a big, obvious change—can be all but invisible when you take another look.

MORE TO EXPLORE

Failure to Detect Mismatches between Intention and Outcome in a Simple Decision Task. Petter Johansson, Lars Hall, Sverker Sikström and Andreas Olsson in *Science,* Vol. 310, pages 116–119; October 7, 2005.

Attention and Awareness in Stage Magic: Turning Tricks into Research. Stephen L. Macknik, Mac King, James Randi, Apollo Robbins, Teller, John Thompson and Susana Martinez-Conde in *Nature Reviews Neuroscience.* Advance online publication; July 30, 2008.

Microsaccades Drive Illusory Motion in the Enigma Illusion. Xoana G. Troncoso, Stephen L. Macknik, Jorge Otero-Millan, Susana Martinez-Conde in *Proceedings of the National Academy of Sciences USA,* Vol. 105, No. 41, pages 16033–16038; October 14, 2008.

For videos of leading magicians performing at the 2007 Magic of Consciousness Symposium, visit **www.mindscience.org/magicsymposium**

COPYRIGHT BENJAMIN A. PARRIS AND GUSTAV KUHN (*sequence of vanishing ball* and *fMRI scans*)

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The Light FANTASTIC

Biological specimens yield extraordinary images in the hands of talented light microscopists

FROM THE EDITORS

Beauty may be in the eye of the beholder, but it is also in the eye of a honeybee, the eggs of a lobster and the surface of petrified wood—as is evident from a selection of images entered in the 2008 Olympus BioScapes Digital Imaging Competition. In its fifth year, the competition honors superior images of living organisms or their components attained with the help of light microscopy.

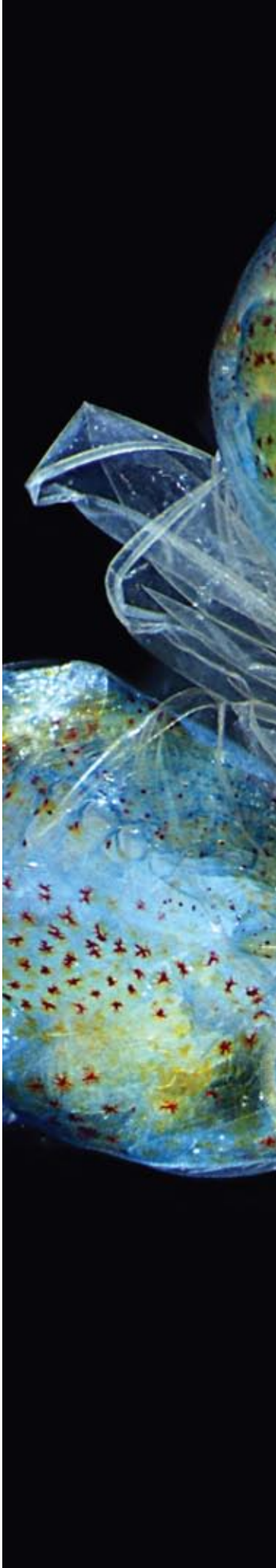
The judges chose 10 winners and awarded honorable mention to many others, evaluating entries based on the scientific value of the images, aesthetics and the difficulty of capturing the information displayed. This year, as in the past, competitors were free to bring out specific features through pseudo-coloring and other computer enhancements.

Here we share our own favorites among the winners and honorable mentions. To see more, visit our Web site at **www.SciAm.com/bioscapes2008**, where we welcome your comments.



▶ LOBSTER EGGS, two to three millimeters in diameter, sit in goo that keeps them together in water. Tora Bardal of the Norwegian University of Science and Technology (NTNU) in Trondheim enhanced the natural colors with dark-field illumination. The round, bluish regions are eyes. Jan Ove Evjemo of NTNU examined the eggs as part of an effort to optimize breeding techniques for a shrinking lobster population.

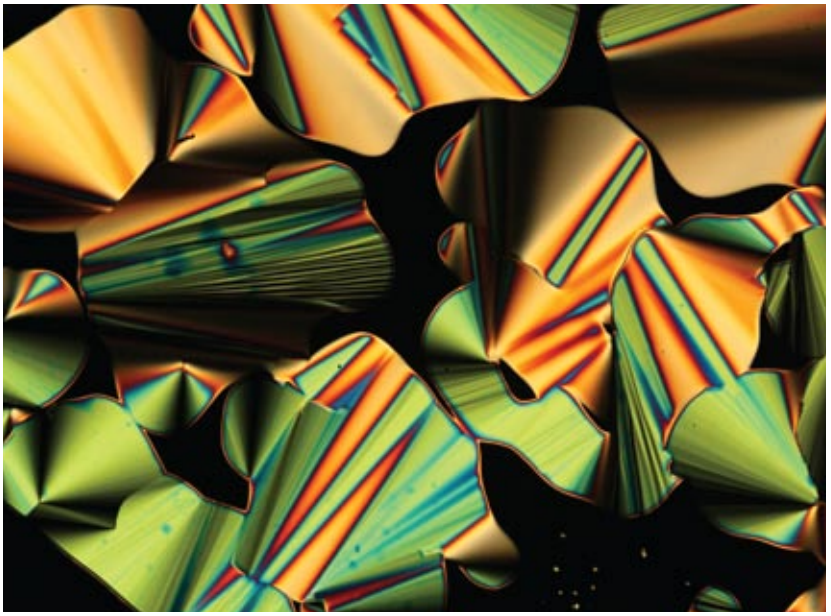
◀ AQUATIC PARASITE *Trichodina pediculus,* imaged by Gerd A. Günther of Düsseldorf, Germany, is roughly 0.09 millimeter in diameter, not counting the cilia; it often colonizes hydra. The surface visible here latches onto a host through a central ring of toothlike "denticles."



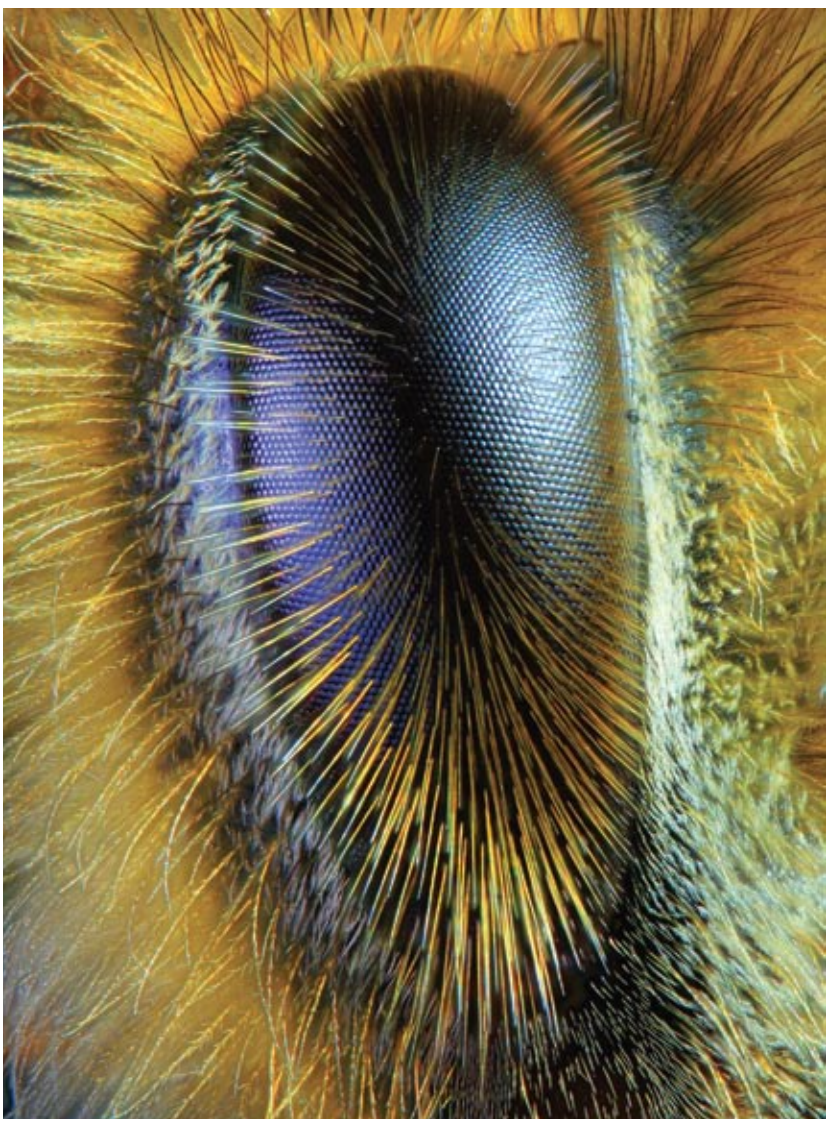
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DNA IN WATER can do interesting tricks. Giuliano Zanchetta of the University of Milan in Italy put short single strands of DNA in solution. The sequences joined to form helices; they also stacked end to end with other nano helices and assembled into the liquid-crystalline aggregates captured here. The region shown measures 0.5 millimeter across.

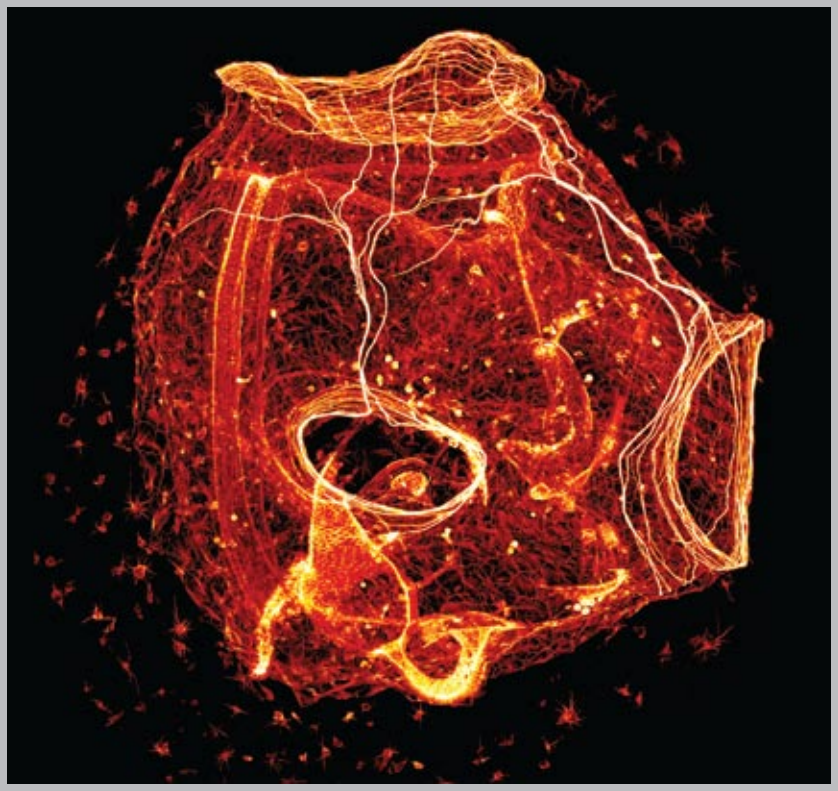


EYE OF A HONEYBEE is approximately five millimeters in diameter. Ralph Grimm of Jimboomba, Australia, combined several images from a digitally recorded stack to make a composite. Grimm relied only on reflected light and did not alter the colors or overall structure. The view, he notes, is "what you'd see if you were really small."

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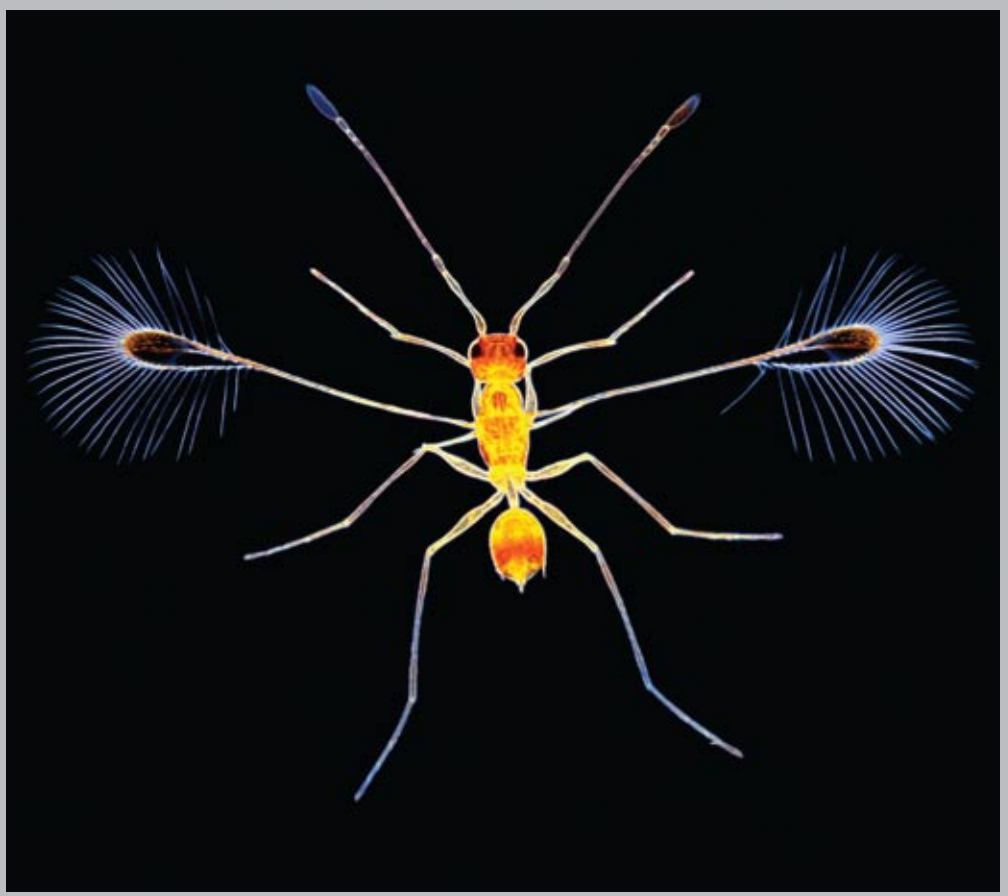


LIVE DAPHNIA, some 0.2 millimeter long, peeks out of an image rendered with dark-field illumination by Earl K. Nishiguchi of Hawaii. Remarkably, Nishiguchi, who has won many honors for his micrographs, got the shot with a 16-year-old microscope that sits in his kitchen.

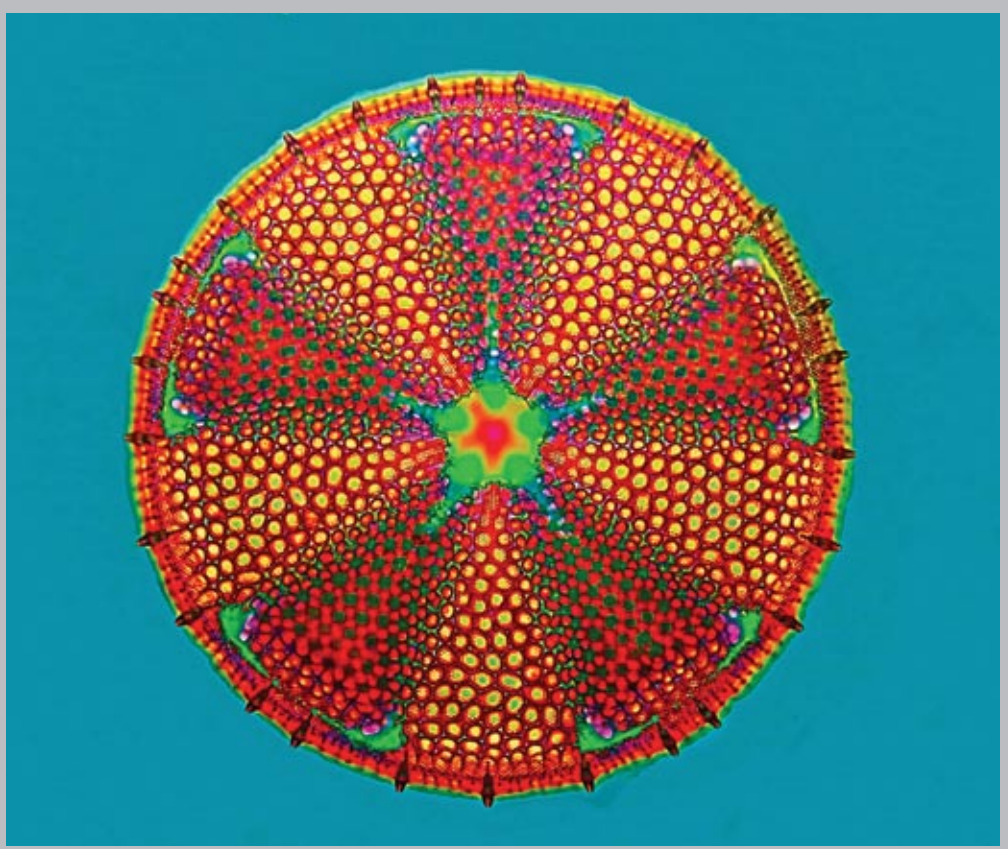


JUVENILE SEA SQUIRT is forming rings of muscles around its openings. The upper orifice is akin to a mouth; the others eject filtered seawater. Michael T. Veeman of the University of California, Santa Barbara, stained for the protein actin and merged 153 optical sections produced by confocal microscopy. The star-shaped cells around the organism help to build an outer coat. Their shape, Veeman says, suggests they may also have a role in sensing the environment or in self-defense.

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FAIRY FLY, a parasitic wasp that deposits its eggs in those of other insects, is approximately 0.2 millimeter long with a wingspan of perhaps three millimeters. It lacks true wings but manages to fly using its feathery appendages. Spike Walker, a freelance photomicrographer in Staffordshire, England, took first prize for the image, made with dark-field illumination to enhance contrast but without stains or color filters.



FOSSIL MARINE DIATOM named *Actinoptychus heliopelta Grunow,* a single-celled alga, lived approximately 20 million years ago, leaving behind its glass (hydrated silica) shell, roughly 0.14 millimeter in diameter. Stephen S. Nagy of Montana Diatoms in Helena brought out its symmetry—and won third place—by combining a stack of five exposures at different focal planes using a procedure called Jamin-Lebedeff interference contrast; the colors reflect relative differences in thickness.

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"ROADS" in this 1.5- by 2.5-centimeter section of petrified wood consist of agatized rock that filled in some cracks. Thomas P. Shearer of Duluth, Minn., a pathologist's assistant with a passion for rocks, created the image, earning second prize. He avoided glare by applying double polarization, in which polarizing filters are placed both on lights and on the lens. The same technique, he says, turns out to dramatically improve the clarity of pathology specimens viewed under a microscope.

For more information about the Olympus BioScapes competition, visit **www.olympusbioscapes.com**

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DRIVING TOWARD Crashless Cars

Next-generation automotive safety technology could give us vehicles that are difficult to crash—and eventually may not need drivers at all **By Steven Ashley**

KEY CONCEPTS

- Smart safety systems on today's high-end autos are taking ever greater control from drivers to avoid collisions or, at least, reduce injuries and fatalities. Within a few years, cars will steer clear of accidents without any driver input at all.
- So-called crashless cars will emerge because of customer expectations of safety, government pressure, crowded roads, an older, less capable population, and the adoption of lightweight vehicles with less crashworthy structures.
- Engineers have meanwhile demonstrated robotic vehicles. Together with the crashless car, this development means that the driverless car cannot be far off.

—The Editors

The empty highway stretches straight out to the horizon, so I take a moment to peek at the electronic display down in the car's center console. I read out the numbers on the screen swiftly and glance back to the windshield, when I see … nothing. A dense fog has swallowed the roadway, and I am driving blind. Before I can feel for the foot brake, an unmistakable warning—a brake-light red rectangle—flashes onto the windshield. Without another thought, I slam hard on the pedal, cursing loudly. My vehicle comes to a hasty halt as a disabled car emerges abruptly from the murk dead ahead.

Before I can even exhale, bright lights burn all around, and laughter rings out incongruously through the passenger cabin. I remember suddenly that I'm sitting inside the VIRTTEX (VIRtual Test Track EXperiment) driving simulator lab at Ford's Research and Innovation Center in Dearborn, Mich. The big, egg-shaped simulator dome enables specialists there to conduct driving tests under totally safe but highly convincing virtual-reality conditions. The disembodied mirth on the intercom is the control-room technicians having a chuckle over my brief discomfiture.

For the past quarter of an hour they have thrown various tasks at me—each one designed to demonstrate the dangers of driving while distracted. One of my jobs—the last one, in fact—had been to look down at the central display when asked and call out the numbers that appeared there without losing control of the vehicle. Glances away from the road that are longer than two seconds double the odds of a crash or near crash.

During the follow-up debriefing, Mike Blommer, technical leader at the VIRTTEX lab, tells me that the windshield alarm that popped up during the final task is a visual alert generated by a forward-collision warning unit on Volvos. The system acts like an electronic guardian angel, monitoring traffic up front with radars and cameras and signaling the driver when it senses danger. The warning's marked resemblance to a standard red brake light is no accident, he notes: "The engineers chose that particular signal because its meaning is intuitively clear to every experienced driver. Even though you'd never seen it before, you knew exactly what it meant and took corrective action."

This system is just one example of the latest generation of advanced safety devices designed to ward off traffic accidents. Although they are currently available on many high-end car models, these technologies are starting to migrate to lower-cost cars and trucks as well. And the next major iteration of collision avoidance technology should be even more effective, as it will be able to engage the brakes automatically without any input from the driver at all. These and related safety capabilities may herald a new era for the automobile, a time in which car owners become increasingly willing to accept automated assistance

KENN BROWN *Mondolithic Studios*

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VIRTUAL SAFETY BUBBLE erected around future cars by smart sensor systems will fend off accidents.

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on the road, even if that means ceding to robotic systems some of their traditional feelings of mastery over their vehicles. Within a few decades, experts say, many advanced cars will be able to avoid most crashes. At some point, in fact, they will drive themselves.

Trends toward Safety

The main motivations for these innovations are clear enough. Some six million motor vehicle traffic accidents occurred in the U.S. in 2006, according to the National Highway and Traffic Safety Administration (NHTSA). Those incidents led to nearly 39,000 fatalities and 1.7 million injuries. And almost 95 percent of the 10.6 million vehicles involved in crashes that year were passenger cars or light trucks. In the meantime, despite continuing calls for greater investment in mass transit, American roads are only growing more crowded. Similar circumstances prevail in the rest of the world, particularly in developing nations, where auto ownership is skyrocketing.

Accident statistics indicate that driver error is the main cause of safety problems on the road, states Jörg Breuer of Mercedes-Benz. "For instance, it can be difficult for the driver to assess how hard to brake when a lead vehicle suddenly slows," he says. "And you lose precious microseconds determining the severity of the danger." Hence, "many people are braking too late, too little or not at all," he explains, so Mercedes and their competitors are working to provide automated braking assistance.

Two trends are also pushing toward greater automation in cars. First, the average age of most of the world's driving populations is rising rapidly. As motorists' faculties and capabilities decline, technology can increasingly take up the slack to keep vehicle occupants—and others on the road—safe.

The second trend is a bit less obvious. Greener, more environmentally responsible cars that consume less energy are currently all the rage. Most such efforts focus on developing more energy-efficient engines, but engineers can achieve much the same effect by building cars that are lighter weight. Unfortunately, such "lightweighting" often results in vehicles with less robust structures that tend to sustain more damage in collisions. Autos that avoid accidents can somewhat compensate for that drawback.

On the other hand, some factors are limiting the speed at which advanced safety technology is coming online. It is still rather expensive. Also, car manufacturers remain wary of any costly legal ramifications that might arise from injuries or deaths caused by safety system failures. And perhaps paramount, automakers are careful not to intrude too much on customers' strong feeling of control over their road machines, so they focus on educating drivers about the benefits of the latest features as they introduce them. This effort comes down to building trust in the new capabilities.

Staying Alive

Some first-generation technologies that help drivers to prevent accidents or lessen the intensity of crash injuries and damage—known in the business as active safety systems—are already familiar. (So-called passive safety features, such as seat belts, air bags, and crumple or crush zones, protect you when a collision occurs.) Antilock brakes (ABS), which entered the market in 1978, improve steerability and hasten deceleration when someone slams on the brakes. "ABS constituted the first time a sensor was allowed to 'feel' a critical driving situation and then act automatically to mitigate it," Breuer says.

Traction-control systems (TCS) were the next major active safety technology to be introduced. They prevent the engine-driven wheels from losing traction and thereby improve overall vehicle control when the driver applies too much gas (engine throttle), producing torque (rotational force) that is beyond what the road-surface conditions can handle.

After TCS came enhanced stability control, or ESC. These systems constantly monitor the angle of the steering wheel and the vehicle's direction; the latter is assessed by the speed of sideways motion, the angle of the car relative to its central axis and how fast the wheels are turning. When an ESC system detects skids, it attempts to short-circuit them by selectively activating the brakes needed to straighten the car's trajectory. It may also step down the engine's power until the car rights itself.

Studies by Mercedes and Toyota indicate that ESC installation results in a 29 to 35 percent reduction in single-vehicle crashes and from 15 to 30 percent fewer head-on collisions, which in the U.S. translates into thousands of lives and tens of billions of dollars saved annually. The marked success of ESC is highlighted by a recent decision by the NHTSA to make the technology standard equipment by 2012 for vehicles below 10,000 pounds gross weight, re-

LIFESAVING TECHNOLOGY

The growing use of automotive safety technology is making itself felt on American roads, according to the NHTSA's "Traffic Safety Facts 2006" report.

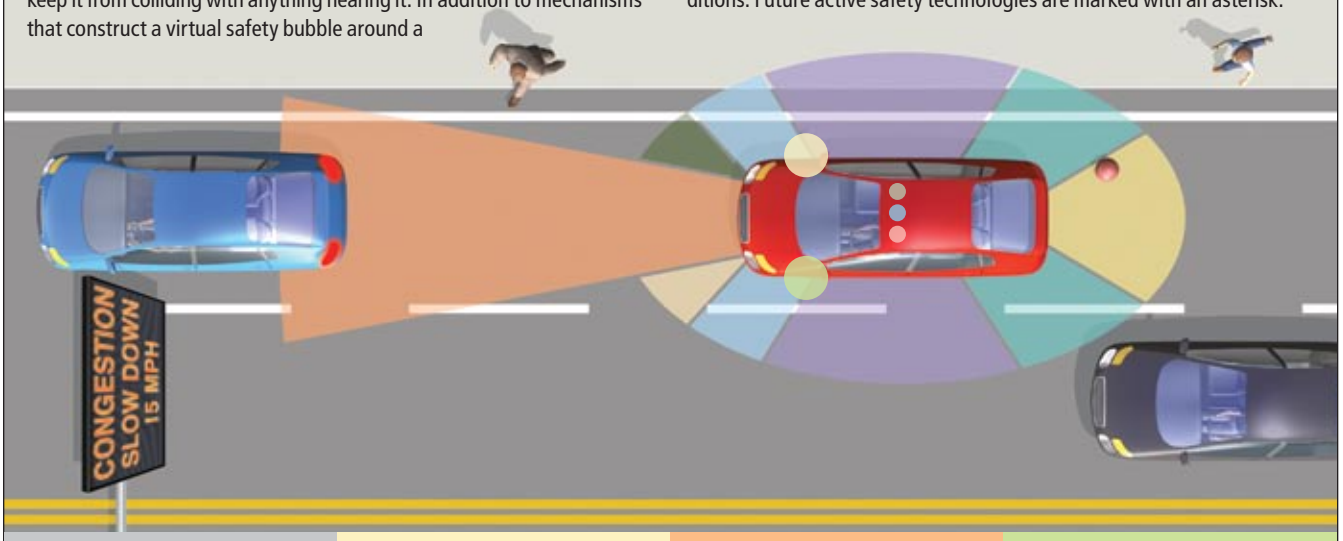
- Fatal crashes declined by **1.7** percent from 2005 to 2006.
- The injury rate per 100 million miles driven decreased by **5.6** percent from 2005 to 2006.
- The fatality rate for vehicle occupants (including motorcycle riders) per 100,000 people shrank by **4.3** percent from 1992 to 2006.
- The injury rate for vehicle occupants (including motorcycle riders) per 100,000 people dropped by **27.8** percent from 1992 to 2006.
- The fatality rate among pedestrians and bicyclists per 100,000 people fell by **51.9** percent between 1975 to 2006.

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[THE GRAND VISION]

DRIVING IN A SAFETY BUBBLE

Existing and next-generation active safety systems—those meant to prevent crashes—could essentially create a safety zone around a car to keep it from colliding with anything nearing it. In addition to mechanisms that construct a virtual safety bubble around a vehicle, some earlier systems, such as the familiar ABS, TCS and ESC technologies, help a car handle more surely and stop faster in hazardous conditions. Future active safety technologies are marked with an asterisk.



ANTILOCK BRAKE SYSTEM (ABS)—improves steerability and hastens deceleration during hard braking	**EMERGENCY BRAKE ASSIST (EBA)**—boosts brake effectiveness during emergency stops	**FORWARD-COLLISION WARNING (FCW)**—detects potential crash and sounds an alarm	**AUTOMATIC BRAKING***—senses potential collision and applies brakes without driver input
TRACTION-CONTROL SYSTEM (TCS)—prevents driver from losing traction when maneuvering	**BLIND-SPOT DETECTOR (BSD)**—a so-called convenience feature that warns when vehicles occupy adjacent lanes	**LANE-DEPARTURE WARNING (LDW)**—sounds alarm when car strays from lane	**LANE-DEPARTURE PREVENTION (LDP)**—stops car from changing lanes when it discerns a hazard coming from behind in the next lane
ELECTRONIC STABILITY CONTROL (ESC)—detects and prevents skids	**BACKOVER DETECTION***—warns driver of an unseen obstruction or person when car is backing up and brakes automatically if necessary	**TRAFFIC-SIGN RECOGNITION (TSR)***—sounds an alert as driver enters a zone where traffic rules have changed	**AUTOMATIC PEDESTRIAN RECOGNITION***—points out pedestrians or animals on the roadway ahead

ports Kay Stepper of Robert Bosch's Vehicle Motion and Safety Division in Farmington Hills, Mich. An expected benefit of the new rule is that ABS and TCS will become standard on all cars and light trucks.

Networked Safety

ESC is, in addition, the key to a new generation of safety systems that take advantage of networked communications among vehicle sensors, actuation devices and computers, Stepper continues. Because ESC uses acceleration, or g-force, sensors that keep watch on the overall motion of the vehicle, it can provide a central monitor-and-controller unit with the information needed to react effectively to looming road threats. "Up until recently, the different safety subsystems in a vehicle have worked independently of one another," he states. "By networking the components together so they can talk to one another, however, we can achieve enhanced capabilities or even totally new functions, often using the same equipment or even less."

Consider an example of this transition: to trigger deployment in a crash, Bosch's current side-impact air-bag system relies on two separate sensors to verify that a side collision is occurring—one in the door that detects pressure and one in the stability-control unit that measures acceleration. "Unfortunately, you have to wait until verification before setting off the air bags, so you lose precious milliseconds, which can be an eternity in a collision," Stepper notes. But in the latest networked approach, a central "black box" controller that monitors vehicle motion can receive information from the ESC's acceleration sensor about yaw—that is, a rotation of the vehicle about its vertical axis that indicates it is sliding sideways—and prepare the side air bags to deploy immediately if the door-pressure sensor goes off.

The automotive industry is just starting to

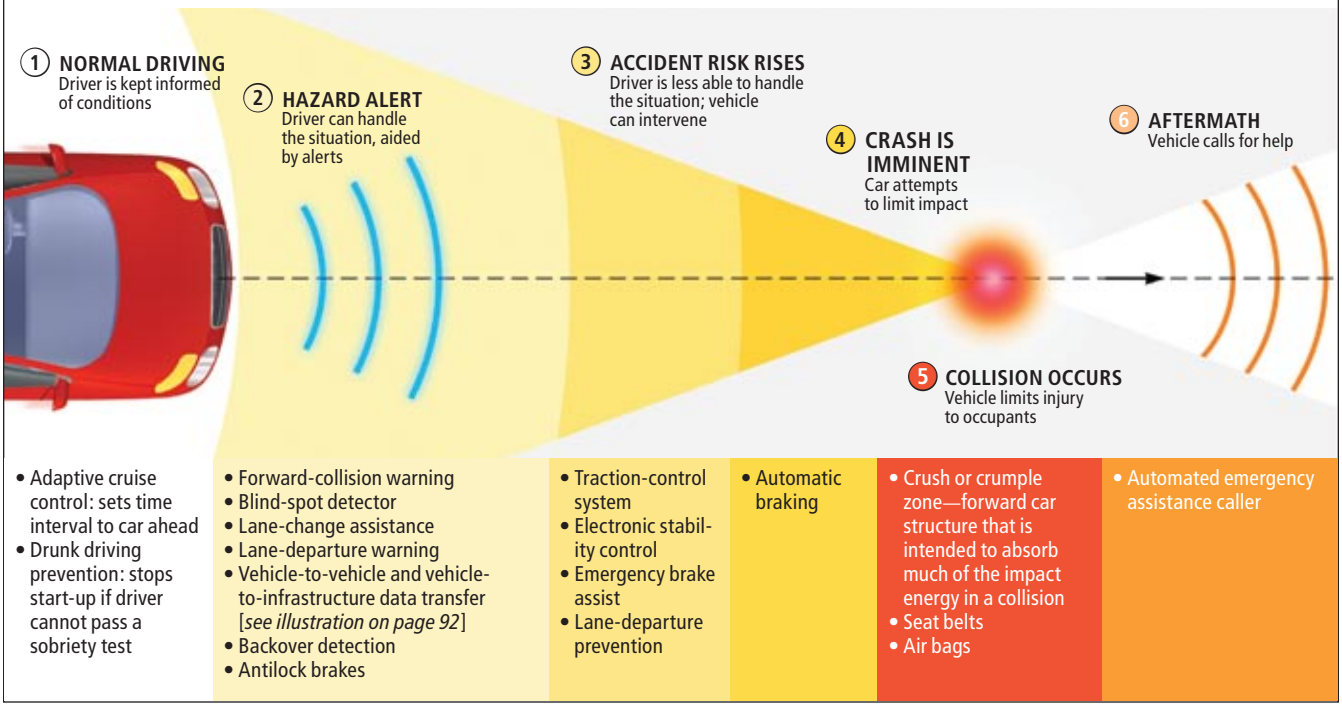
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[TIMELINE]

WHAT WORKS WHEN

Car safety experts divide a potential traffic collision into six stages. In each, different safety systems could come into play to prevent the crash or, as a last resort, limit injuries. Common "passive" systems, such as seat belts and air bags, fulfill the latter job. Features typically considered conveniences, such as adaptive cruise controls and blind-spot detectors, can be helpful for avoiding accidents as well.



exploit these potential synergies by integrating a number of previously independent safety subsystems into networks so that critical information will be available to all of them. The change, Stepper concludes, should save on costs "because fewer sensors will be needed to accomplish the same tasks."

Collision Warning

Among the more exciting of the safety systems are technologies that warn of, and help to avoid, collisions with vehicles or other hazards up ahead—versions of which I tried out in the Ford simulator as well as a couple of times on different test tracks. Forward-collision warning systems are based on the relatively new adaptive cruise-control devices that rely on radar data to maintain a preset distance or time gap between two vehicles.

Newer "stop and go" adaptive cruise controls make riding in slow-moving traffic considerably easier, because they can follow the car ahead precisely as it halts and starts up again. The addition of a camera and sophisticated software-control algorithms makes for a basic collision warning system.

These devices need to combine radars with cameras because each brings a different capability, says Dean McConnell of Continental Automotive Systems in Auburn Hills, Mich. "Radars can tell whether something is out there or not, and they can measure the distance to an obstacle, but they are not so great at classifying what that object is. The video camera system can distinguish between something important, like a car, and something that's not, say, a manhole cover in the street." Only together can they determine with confidence when dangerous frontal collisions are likely and that braking is needed, he explains.

In typical installations, McConnell notes, a long-distance, 77-gigahertz, microwave radar sensor monitors out to 400 to 650 feet ahead and a shorter-range, 24-gigahertz, radar unit scans several tens of meters up front. Their wide-angle video cameras can recognize objects that are about 130 to 165 feet away. When a warning system determines that a car is closing in too fast on the one ahead, it jogs the brake pedal, flashes a braking alert or activates other signals, and prepares the brakes for instantaneous activation by prepressurizing the hydraulic brake lines. If the driver takes no action and collision is imminent, then the system slows the

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vehicle automatically to at least reduce the impact of any collision. Many liken the technology to extending the car's crush zone forward.

Automatic Braking

Today's collision warning systems point the way toward future active safety systems that automatically hit the brakes or steer cars back into their lanes to avoid accidents altogether. But successfully fielding fail-safe, all-speed versions of such technologies is considerably more problematic and still five or 10 years away.

Volvo has taken an initial swipe at automated braking in its XC60 model with the City Safety feature, a low-speed collision avoidance and mitigation system that operates below 20 miles per hour. City Safety is intended to address the issue of slow—often urban, hence the name—fender benders, which in many places, account for around three quarters of all car collisions, says Thomas Broberg of Volvo in Gothenberg, Sweden. Most fender benders are caused by distracted drivers. Although these accidents result in few deaths, they often cause whiplash and, Broberg notes, "are very costly to society."

City Safety has an infrared laser range finder that sends out beams and looks for reflections from objects that are 20 to 25 feet in front of the vehicle. A receiver measures the speed at which the two bodies are closing in on each other and, if necessary, prepares the emergency brakes to respond quickly. "If the driver does not do anything in this situation, the system will brake automatically," Broberg says. "It does not give a warning at this point, because it would only confuse the driver." Afterward the system notifies the driver that City Safety has kicked in.

Moving up to a full-on, all-speed autonomous braking system will be difficult, Broberg says, because ensuring that any action it takes in a critical situation is the right move is challenging. "It's easy to make a car brake automatically," he observes. "The trick is to ensure that it doesn't brake when it's not supposed to" and to ensure that "it will take the correct action every time." So far Volvo, other automakers and safety system suppliers are still testing to be sure that their systems are ultrareliable. For example, they are putting the systems into cars—often owned by regular customers—in different environments all over the world. Most of the time the new systems are inactive, but they record whether the correct decisions would have been made.

Keeping in the Lane

Front-facing video cameras serve as key components in devices that warn the driver when the vehicle is leaving its lane. The cameras track lane markers and note when the vehicle deviates from the pathway they define.

Nissan, which was one of the first car manufacturers to introduce such technology, is bringing out an upgraded lane-keeping technology, reports Alex Cardinali of Nissan North America in Nashville, Tenn. "Our new lane-departure prevention system stops drivers from inadvertently drifting out of their lanes because, for example, of inattention, distraction or drowsiness. It intervenes by providing brake input on one side of the car, which creates a yawing motion that brings the car back into the lane." Be-

CAR CRASHES: A LINGERING MENACE

- Nearly **six million** traffic accidents were reported to the police in the U.S. in 2006.
- Around **40,000** deaths are caused by car accidents every year.
- Every **12** minutes one person dies because of an automobile accident, and such incidents injure someone every 14 seconds.
- More than **one quarter** of all drivers are involved in car accidents in any five-year period.
- About **two out of five** road fatalities occur because of a drunk driver.
- Approximately **30** percent of automobile accident deaths can be attributed to speeding.
- More than **one third** of car accident fatalities result from reckless driving that causes the vehicle to go off the road.





COLLISION WARNING, **the red light strip reflected on the windshield in the left photograph, warns of a potentially hazardous obstacle in the roadway ahead during a "drive" in a Ford virtual-reality simulator. The navigation screen in the right photograph is linked to Honda's new multiview camera system and displays a wide-angle, wraparound view from the back and rear sides of the vehicle.**

COURTESY OF FORD MOTOR COMPANY (*collision warning*); COURTESY OF HONDA MOTOR CO., LTD (*navigation screen*)

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LEGAL ROADBLOCKS

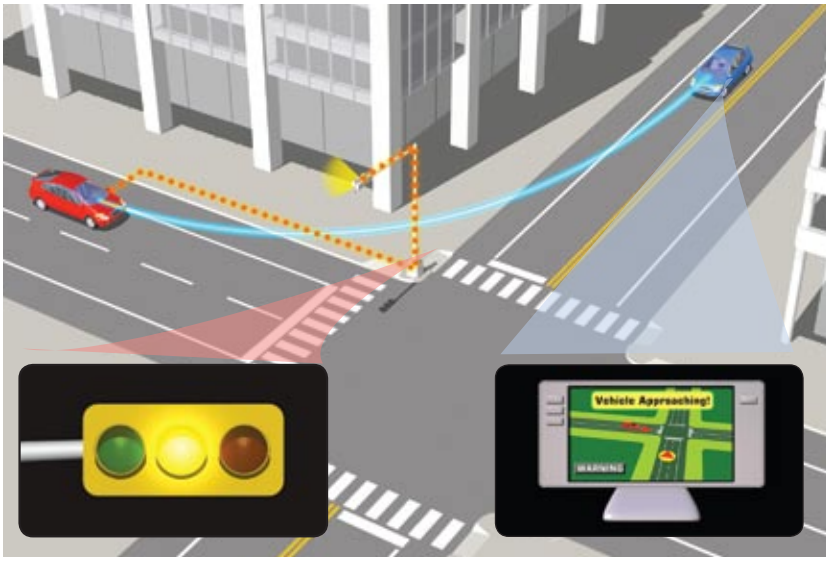
Introducing automated car safety systems poses daunting product liability issues for automakers and their suppliers. When air bags were first introduced, for example, no one realized the dangers posed to child passengers from air bags that deploy at excessive speeds. Much court litigation resulted until safer practices, such as placing the kids in the rear seat, were widely adopted.

To limit unintended consequences, manufacturers today prefer to introduce a feature only after (1) enough research has been conducted to prove that the new technology truly enhances safety, (2) the NHTSA sanctions its use, and (3) consumers are fully educated about its benefits and limitations.

sides monitoring the lane markings with a camera mounted above the rearview mirror, the unit takes into consideration both the vehicle's speed and the driver's steering manipulations.

I had a chance to demo a similar system during a drive just outside of Bosch's U.S. test facility in the softly rolling countryside south of Detroit. With a trio of Bosch engineers sitting in the passenger seats, we plied a nearly empty stretch of arrow-straight, two-lane roadway. When the coast was clear, the researcher beside me engaged the system with a few laptop keystrokes. Then I steered the car into the next lane, and the steering wheel and seat started shaking as if we had just driven onto a "washboard" dirt road. The message was clear: get back in your lane. We went on to try out several similar implementations of the same basic concept, except that the alarm signals were beeps, chimes and dashboard lights. Flipping the turn signal overrides the lane-keeping function.

I soon found out that I was most comfortable with the slot-car-like action of what the researcher called "bathtub mode," referring to the sloping sides of a graph of the machine's responses to steering deviations on his laptop screen. Each time I turned the wheel to point the car out of my lane, a countervailing force very smoothly directed the vehicle back into my lane. The engineers smiled with satisfaction when I remarked that I would find it "very easy to get used to riding in the center of the bathtub."



SIXTH SENSE FOR DRIVERS: Automakers, including Toyota and General Motors, are testing traffic safety systems that would transmit wireless alerts between nearby vehicles and from the roadway infrastructure to vehicles. Such signals could warn drivers of hazards with audible alarms and dashboard icons (*insets*). If a driver fails to respond to an alert for, say, a stopped car blocking the roadway around a bend, the car could bring itself to a stop, avoiding a collision. Such vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technology, could send out vehicle speed, GPS location and braking information to receivers within a quarter mile or so.

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Avoiding Being Blindsided

A counterpart to lane-keeping systems are blind-spot detection systems, which use side-mounted ultrasonic or radar sensors to view the adjacent lanes and notify drivers of vehicles in their blind spots. In most such systems now on the market, warning lights in the side-view mirrors switch on when the vehicle occupies those zones. McConnell says that blind-spot detectors are gaining in popularity among drivers who have tried them, but the technology "might actually develop faster in the commercial market, because all trucks have big blind spots."

An extension of the blind-spot technology is lane-change assistance provided by a system that tells drivers when cars in adjacent lanes are rapidly gaining on them and even prevents them from steering into the lanes. In this case, McConnell says, the sensing area is expanded "to a couple of car lengths, maybe 165 feet, behind." A related technology is designed to avoid the horrific situation when a driver backs a car over a small, unseen child, often playing in the driveway. These backover protection systems can detect the child or an object before contact and halt the vehicle. He reports that the NHTSA is conducting discussions with the automakers and their suppliers to address these terrible, but—thankfully—fairly rare incidents.

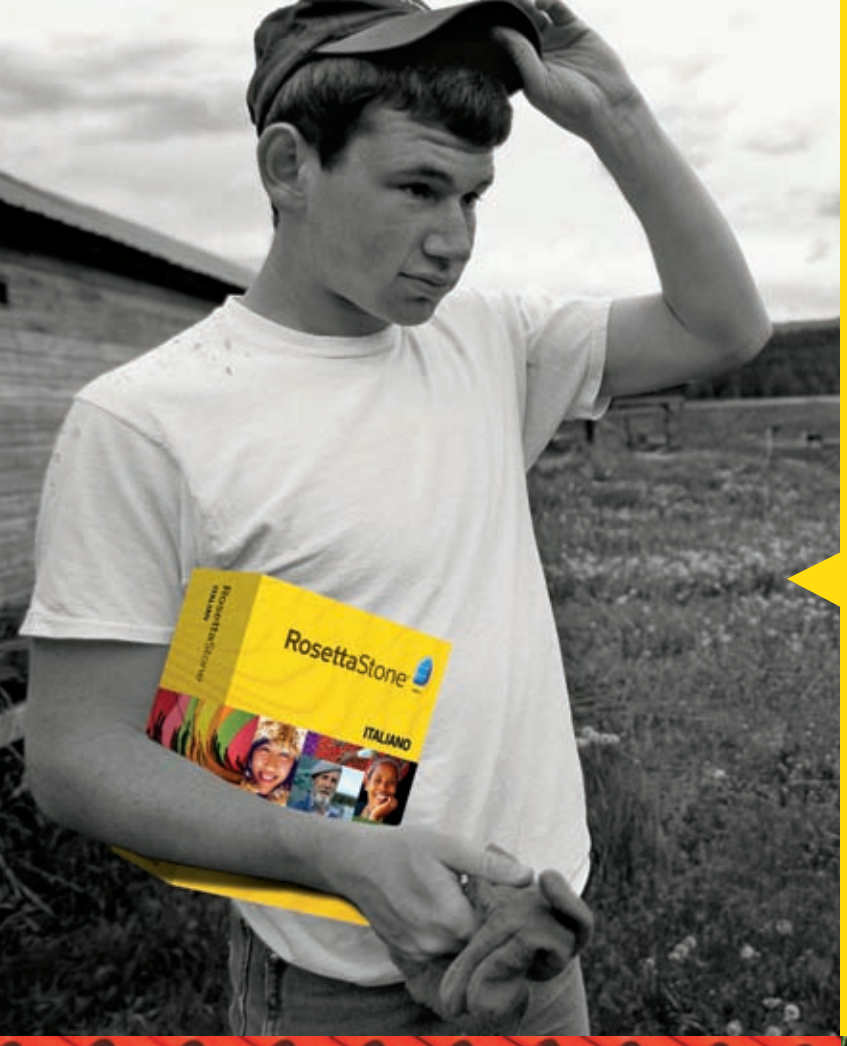
McConnell predicts that the future will see safety systems that identify and avoid pedestrians and animals, such as deer, on the roadway, even at nighttime, as well as traffic-sign recognition systems that, for example, prevent drivers from running stop signs and lights.

The combination of all these advanced sensor systems, particularly if they were networked, could establish a virtual "safety bubble" around a vehicle, one that could detect nearly any hazard in the vicinity. But such an onboard system would probably be complex and costly, perhaps more than car owners would want to spend.

Car Talk

Because of the expense, a number of auto manufacturers are investigating an alternative, lower-cost approach that involves linking vehicles and the roadway infrastructure through wireless communications not much more sophisticated than text messaging. Rather than relying on a car's own onboard sensor suite,

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"BOSS" ROBOTIC VEHICLE (*left*), which won last year's DARPA Urban Challenge autonomous vehicle competition, is the forerunner of future driverless cars and trucks that could be available in a decade. Such automated vehicles will be capable of "platooning," or riding in close formation without driver intervention, as was demonstrated several years ago on a San Diego freeway (*right*). These kinds of "intelligent highway" technologies would allow vehicles to save space and limit accidents on the nation's increasingly traffic-bound roads.

says Alan Taub, executive director of General Motors Research and Development, "why not just find out what's happening in the neighborhood by querying other vehicles and nearby road signs and intersections?"

Such vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) systems "would allow drivers to see beyond the visual horizon. For example, say there's a vehicle stopped in the street ahead, but it's just around the corner," Taub says. "The onboard system may not sense it in time, but a nearby passing car probably would." Or an intersection management system with a built-in wireless communications node could inform an inattentive driver that his or her car is about to run a red light. It could even apply the brakes, if that were desirable [*see illustration on page 92*].

Part of the genius of the concept is that it is low-tech: cars and roadways would be fitted with just basic sensors such as Global Positioning System (GPS) location devices, some computing power, and compatible wireless short-range radio transmitter and receiver units. And not every vehicle needs to be so equipped at first, Taub notes: "You get some safety benefits even from only 5 or 10 percent penetration into the vehicle population."

But the approach has drawbacks as well. Both systems require that all the car companies that sell vehicles in a country agree to consistent communications standards, which at the very least will take time to establish. And although outfitting cars to operate in roadway V2I networks would not cost too much, installing the needed devices across the entire road infrastructure would probably be expensive. One estimate indicates that a nationwide V2I system in the U.S. would cost a trillion dollars to build.

Nevertheless, talks on V2V technology are ongoing among the interested parties, including Toyota, General Motors, Nissan and others, and research organizations in Japan and China, in particular, are developing V2I prototypes.

Driving on Auto

Once the safety systems and autonomous navigation technologies now under development achieve truly bulletproof reliability and drivers come to fully accept them, it is not much of a jump to foresee vehicles that can drive themselves. Indeed, researchers have already shown that such cars are feasible.

In 2007 a tricked-out Chevrolet Tahoe nicknamed "Boss" and several similar driverless vehicles successfully navigated through a realistic city streetscape in Victorville, Calif., one complete with other cars and even traffic jams. The autonomous cars and trucks were competing in the Defense Advanced Research Projects Agency's Urban Challenge, a race designed to demonstrate that robot road vehicles can become practical. Soon afterward General Motors CEO G. Richard Wagoner, Jr., predicted his company will market autonomous vehicles within 10 years. That prognostication may be a bit optimistic, but his statement surely points the way to real robotic cars in the not too distant future. ■

Steven Ashley is a staff editor and writer.

MORE TO EXPLORE

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COURTESY OF GEREAL MOTORS (*GM Chevrolet "Boss"*); COURTESY OF BILL STONE *California Path* (*platooning cars*)

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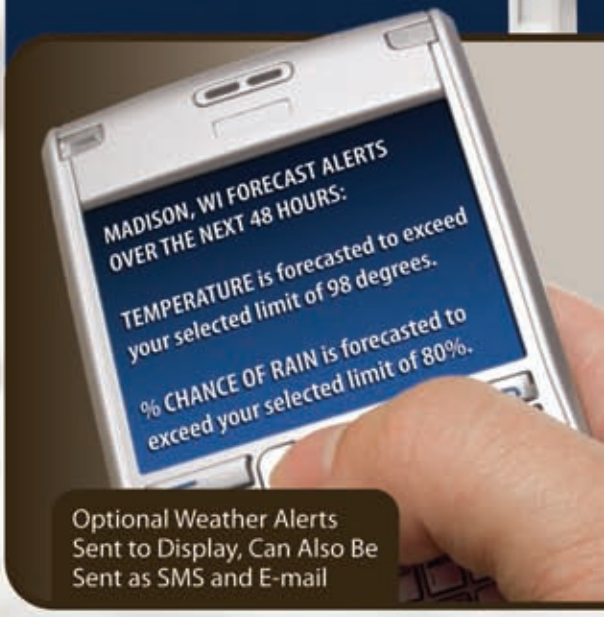
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Taking Wing

At last, fossil and genetic findings elucidate the evolution of bats—and settle a long-standing debate over the origins of flight and echolocation

BY NANCY B. SIMMONS

KEY CONCEPTS

- Bats are the only mammals that can fly. Scientists have therefore been eager to learn how they evolved from their terrestrial ancestors.
- Until recently, however, even the oldest fossil bats still looked essentially like modern bats.
- New fossils have revealed a species that is helping to connect the dots between bats and their nonflying forebears.
- Findings from genetics and developmental biology have further illuminated bat origins, elucidating their place in the mammal family tree and the process by which the bat wing may have evolved.

—The Editors

Survey the sky at twilight on a summer's eve, and you just might glimpse one of evolution's most spectacular success stories: bats. With representatives on every continent except Antarctica, they are extraordinarily diverse, accounting for one in every five species of mammal alive today. The key to bats' rise to prominence is, of course, their ability to fly, which permits them to exploit resources that other mammals cannot reach. But their ascension was hardly a foregone conclusion: no other mammal has conquered the air. Indeed, exactly how these rulers of the night sky arose from terrestrial ancestors is a question that has captivated biologists for decades.

Answers have been slow in coming. This past February, however, my colleagues and I unveiled two fossils of a previously unknown species of bat that provides vital insights into this mysterious transformation. Hailing from Wyoming, the species—dubbed *Onychonycteris finneyi*—is the most primitive bat ever discovered. These fossils and others, together with the results of recent genetic analyses, have now led to a new understanding of the origin and evolution of bats.

Winged Wonder

To appreciate just how distinctive bats are, consider one of their trademark traits: wings. A few mammals, such as flying squirrels, can glide from tree to tree, thanks to a flap of skin that connects their front and hind limbs. And in fact, experts generally agree that bats probably evolved from an arboreal, gliding ancestor. But among mammals, bats alone are capable of powered flight, which is a much more complex affair than gliding. They owe this ability to the construction of their wings.

The bones of a bat's wing consist of greatly elongated forearm and finger bones that support and spread the thin, elastic wing membranes. The membranes extend backward to encompass hind limbs that are quite a bit smaller than those of a terrestrial mammal of comparable body size. Many bats also have a tail membrane between their hind legs. A unique bone called the calcar projects from the bat's heel to support the trailing edge of this membrane. By moving their fingers, arms, legs and calcars, bats can maneuver their wings in innumerable ways, making them superb fliers.

Most bats can also echolocate. By producing high-pitched sounds and then analyzing the returning echoes, these nocturnal animals can detect obstacles and prey much better than by using vision alone. (Contrary to the expression "blind as a bat," all bats can see.) More than 85 percent of living bat species use echolocation to navigate. The rest belong to a single family—the Old World fruit bats, sometimes called flying foxes, which apparently lost the ability and



KIM TAYLOR *NPL/Minden Pictures*

WINGED VICTORY: Bats hold dominion over the night sky, thanks to their ability to fly.

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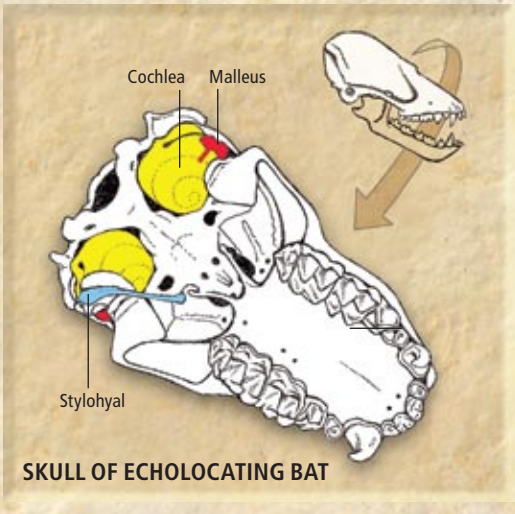


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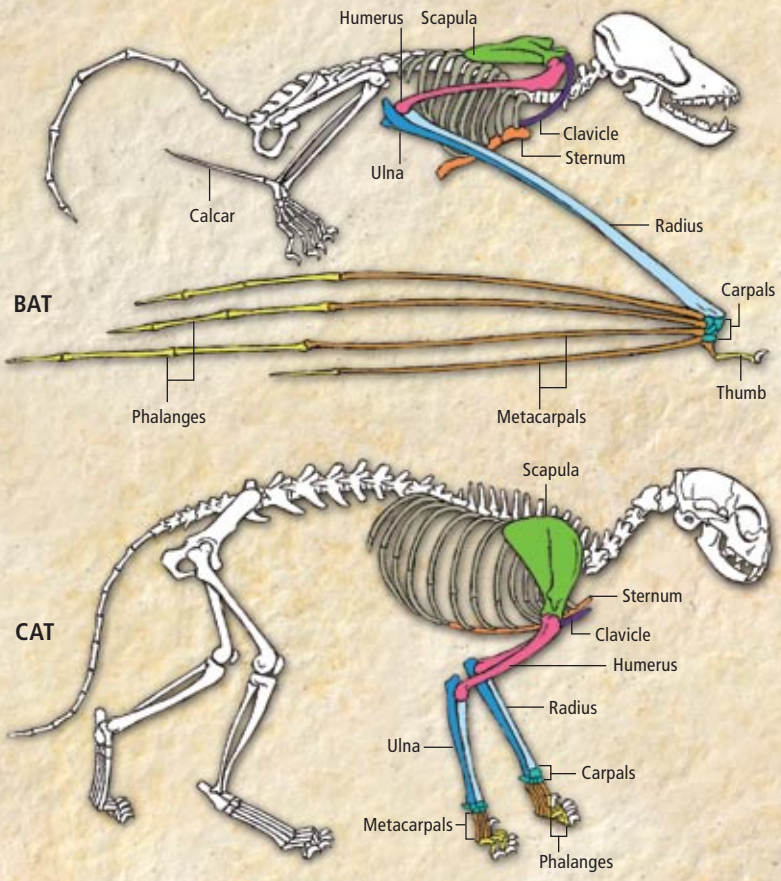
[ANATOMY BASICS]

Mammal Makeover

The descent of bats from land-dwelling mammals ranks among evolution's grandest transformations. Most of the modifications of the bat skeleton are related to flight (*colored bones*). But three bones in the throat and ear—namely, the stylohyal, malleus and cochlea—changed, too, expanding in ways that permitted the evolution of echolocation (*inset*).



SKULL OF ECHOLOCATING BAT



[THE AUTHOR]



Nancy B. Simmons is chair of the division of vertebrate zoology and curator in charge of the department of mammalogy at the American Museum of Natural History in New York City. Her research focuses on understanding the evolution and diversity of bats. Simmons specializes in the anatomy of fossil and living bats and has conducted extensive fieldwork in the rain forests of South America. She also works with DNA sequences to untangle relationships among bat species.

instead rely strictly on sight and smell to find the fruit and flowers they feed on.

Echolocating bats have a distinctive suite of anatomical, neurological and behavioral characteristics that enable them to send and receive high-frequency sounds. Three bones in the skull have undergone modification. The first is the stylohyal, a long, slender bone that connects the base of the skull with an array of small bones—collectively termed the hyoid apparatus—that support the throat muscles and voice box. In most echolocating bats, the upper tip of the stylohyal is expanded into a kind of paddle that helps to anchor the hyoid apparatus to the skull.

The other two bones that bear the signature of echolocation occur in the ear. All mammals perceive sound by way of a chain of bones, known as ear ossicles, that transmit sound between the eardrum and the fluid-filled inner ear. The malleus is the first bone in this chain, and in echolocating bats it has a large, bulbous projection that helps to control its vibration. Once sounds pass through the ear ossicles, they travel to the inner ear, where they impinge on a coiled, fluid-filled structure known as the cochlea (Latin for "snail") that contains special nerve cells responsible for sound perception. When compared with other mammals, echolocating bats have a cochlea that is enlarged relative to other skull structures, which makes them better able to detect high-frequency sounds and to discriminate among different frequencies of these sounds.

Which Came First?

The revelation more than 60 years ago that most of the world's bats can "see with sound" made clear that echolocation contributed significantly to the great evolutionary success and diversity of bats. But which of the two key bat adaptations—flight and echolocation—came first, and how and why did they evolve? By the 1990s three competing theories had emerged.

The flight-first hypothesis holds that bat ancestors evolved powered flight as a way of improving mobility and reducing the amount of time and energy required for foraging. Under this scenario, echolocation evolved subsequently to make it easier for early bats to detect and track prey that they were already chasing in flight.

In contrast, the echolocation-first model proposes that gliding protobats hunted aerial prey from their perches in the trees using echolocation, which evolved to help them track their quarry at greater distances. Powered flight evolved later, to increase maneuverability and to simplify returning to the hunting perch.

The tandem-development hypothesis, for its part, suggests that flight and echolocation

ROBERT S. VOSS (*Simmons*); PATRICIA J. WYNNE (*skeletons*)

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evolved simultaneously. This idea is based on experimental evidence showing that it is energetically very costly for bats to produce echolocation calls when they are stationary. During flight, however, the cost becomes nearly negligible, because contraction of the flight muscles helps to pump the lungs, producing the airflow that is required for intense, high-frequency vocalizations.

The only way to test these hypotheses about the origins of flight and echolocation is by mapping the distribution of relevant traits—wings and enlarged cochleas, for example—onto a family tree of bats to determine the point at which they evolved. Back in the 1990s, we simply did not have any fossils of bats that had some of these signature characteristics but not others.

Bat fossils are extremely rare. Ancient bats, like their modern counterparts, were small and fragile, and they tended to live in tropical habitats, where decay occurs very rapidly. Just about the only way a bat can become fossilized is if it dies in a place where it is swiftly covered with sediment that protects it from scavengers and microorganisms alike.

Until recently, the oldest and most primitive bat on record was the 52.5-million-year-old *Icaronycteris index,* named for the boy of Greek legend who flew too close to the sun. *Icaronycteris* was discovered in the 1960s in lake deposits in Wyoming's famed Green River Formation, whose fine-grained mudstone and limestone rocks have yielded beautifully preserved fish, plants, mammals, insects, crocodiles and birds.

For the next four decades *Icaronycteris* formed the basis for understanding the earliest stage of bat evolution. Ironically, however, perhaps the most remarkable thing about *Icaronycteris* is just how much this ancient beast resembles extant bats. The shape of its teeth indicate that it ate insects, as do most bats today. Its limb proportions are similarly modern, with long, slender fingers, elongated forearms and diminutive hind legs. The creature's scapulas (shoulder blades), sternum (breastbone) and rib cage also attest to a fully developed ability to fly. And it possessed the requisite anatomy for echolocation.

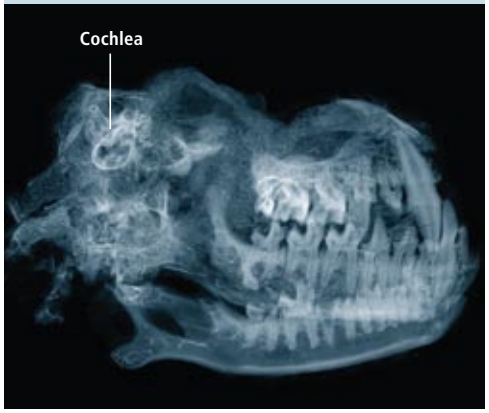
In fact, if it were alive today, *Icaronycteris* would be hard to tell apart from other bats. Its most distinctive feature is a tiny claw on the index finger (hence the species name *index*). Most bats retain a claw only on the thumb. Over time, the tips of the other four fingers were reduced to thin, flexible rods or nubs completely enclosed in the wing membrane. *Icaronycteris*'s index claw seems to be a holdover from a terrestrial ancestor.

Filling the Gap

In retrospect, *Icaronycteris* was never much of a "missing link." But another fossil bat from the Green River Formation would turn out to fit that description nicely. Enter *Onychonycteris*. The two known specimens, unearthed by private collectors in the past decade and later made available for scientific study, were discovered in the same rock layer that yielded *Icaronycteris* and are thus considered to be of comparable antiquity. *Onychonycteris,* however, has a combination of archaic and modern traits that make it exactly the sort of transitional creature evolutionary biologists have longed for.

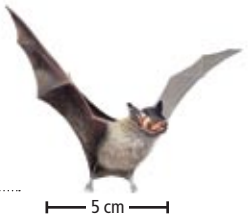
I was fortunate enough to lead the team that described and named *O. finneyi*. We chose the genus name *Onychonycteris* ("clawed bat") because the fossil displays claws on all five fingers, just as its terrestrial predecessors did. The presence of these claws is not the only feature of *Onychonycteris* that recalls nonflying mammals. Most bats have very long forearms and tiny hind limbs. *Onychonycteris,* however, has proportionately shorter forearms and proportionately longer hind limbs than those of other bats. Compared with other mammals, the limb pro-

INSIDE LOOK at the skull of the fossil bat *Hassianycteris,* as revealed by a high-resolution x-ray, shows that an ear bone known as the cochlea is enlarged—an indication that this animal could echolocate. Researchers long wondered whether bats evolved echolocation before or after flight. But like *Hassianycteris,* all bat fossils known before 2008 had signatures of both skills.

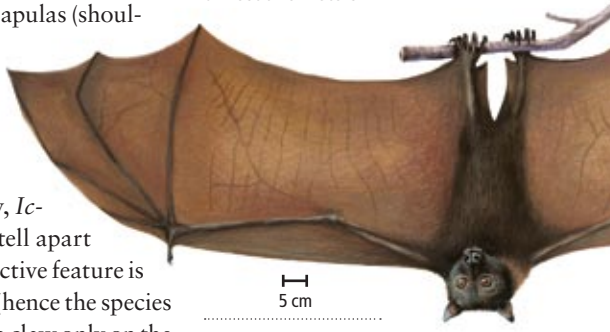


EXTREME BATS

SMALLEST
Craseonycteris thonglongyai, the bumblebee bat, weighs less than a penny.



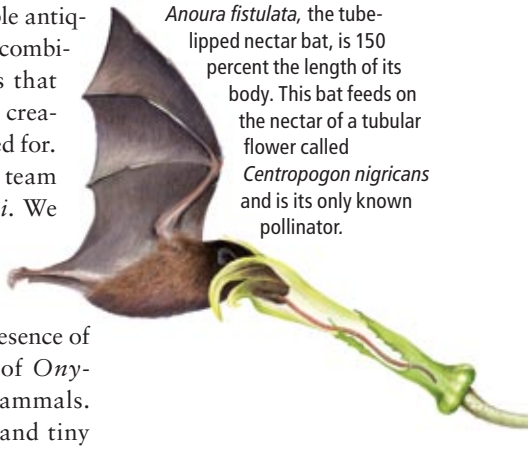
LARGEST
Pteropus vampyrus, the large flying fox, has a wingspan of almost two meters.



LOUDEST
Noctilio leporinus, the greater bulldog bat, utters a high-frequency screech that can be more than 140 decibels—100 times louder than a rock concert.

MOST GREGARIOUS
Tadarida brasiliensis, the Mexican free-tailed bat, lives in colonies composed of up to millions of individuals. Bracken Cave outside of San Antonio, Tex., houses 20 million of these creatures—the largest colony known.

LONGEST TONGUE
At 8.5 centimeters, the tongue of *Anoura fistulata,* the tube-lipped nectar bat, is 150 percent the length of its body. This bat feeds on the nectar of a tubular flower called *Centropogon nigricans* and is its only known pollinator.



COURTESY OF JÖRG HABERSETZER *Senkenberg Research Institute* (*x-ray*); LILA RUBENSTEIN (*bats*); SOURCE: NATHAN MUCHHALA AND MURRAY COOPER (*A. fistulata*)

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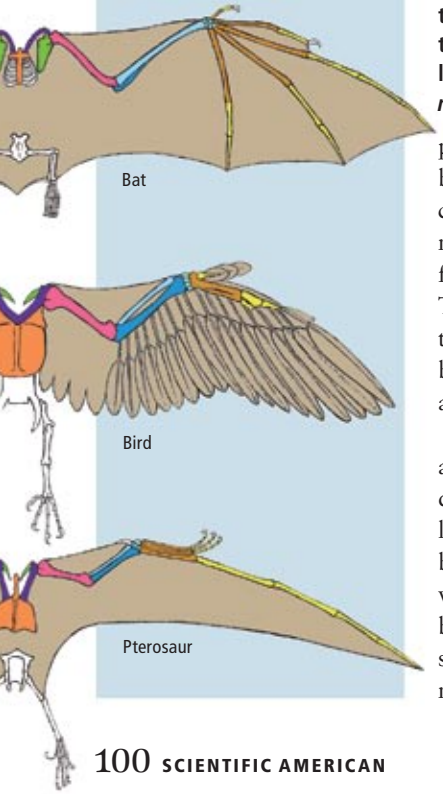
Bats would have had few competitors for the rich resources of the Eocene night.



MISSING LINK: **The recently discovered *Onychonycteris finneyi*—the most primitive bat on record—bridges the gap between modern bats and terrestrial mammals. Features such as greatly elongated fingers and the form of the rib cage and shoulder indicate that it was capable of powered flight. Yet it retains relatively long hind limbs and claws on all five of its fingers—holdovers from an earthbound ancestor. *Onychonycteris* also lacks the telltale traits of echolocation, revealing that flight evolved before echolocation.**

FREQUENT FLIERS

Among vertebrates, flight has evolved independently in three separate lineages: bats, birds and pterosaurs. Though superficially similar, the wings of the animals are structurally distinct. In bats the elongated forearm and second to fifth fingers form the primary scaffolding for the wing. The bird wing, in contrast, is supported mostly by the bones of the forearm and the hand. And the pterosaur wing rests largely on the hand bones and fourth finger.



portions of *Onychonycteris* are intermediate between those of all previously known bats (including *Icaronycteris*) and those of arboreal mammals that rely heavily on their forelimbs for locomotion, such as sloths and gibbons. These animals hang from branches much of the time as they climb around in the trees. Perhaps bats evolved from arboreal ancestors that used a similar form of locomotion.

Despite these primitive limb features, other aspects of the anatomy of *Onychonycteris* indicate that it was capable of powered flight. Its long fingers would have supported wing membranes, and robust clavicles (collarbones) would have helped anchor the forelimbs to the body. Meanwhile a wide rib cage and a keeled sternum would have supported large flight muscles, and a faceted scapula would have secured other specialized, flight-related muscles.

Additional clues to how *Onychonycteris* traveled come from the proportions of its arm and finger bones, which reveal that the animal's wings had a very low aspect ratio and relatively small tips. Among living bats, only mouse-tailed bats possess similarly short and broad wings. These animals have an unusual gliding-fluttering flight style involving brief glides between periods of flapping flight. Our best guess is that *Onychonycteris* flew the same way. It may be that gliding-fluttering flight was the transitional mode of locomotion between the gliding of prebat ancestors and the continuous flapping flight seen in most modern bats.

Beyond illuminating how early bats flew, *Onychonycteris* has brought some much-sought-after evidence to bear on the debate over when

COURTESY OF AMERICAN MUSEUM OF NATURAL HISTORY AND ANIKA HEBS *Senkenberg Research Institute (fossil)*; PATRICIA J. WYNNE (*wings*)

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flight and echolocation emerged. Unlike the other known bats that date back to the Eocene, the epoch spanning the time from 55.8 million to 33.5 million years ago, *Onychonycteris* seems to have lacked all three of the bony correlates of echolocation. It has a small cochlea and a relatively small protrusion on the malleus, and its stylohyal lacks an expanded tip. Yet features of its limbs and thorax clearly indicate that it could fly. *Onychonycteris* therefore seems to represent a stage in early bat evolution after flight had been achieved but before echolocation evolved. Fossils have finally given us an answer: flight first, echolocation later.

Ancient Diversity

The emergence of flight and echolocation set the stage for a dazzling adaptive radiation of bats. Such rapid periods of diversification are known to occur after a breakthrough adaptation. Living bats are classified into 19 families; fossil bats comprise an additional seven families. Remarkably, time-calibrated studies of the DNA sequences of multiple genes indicate that all 26 of these groups were already distinct by the end of the Eocene. This "big bang" of diversification is unprecedented in mammalian history.

Flight and echolocation certainly were not the only factors contributing to this radiation, however. The origin of these major bat lineages apparently coincided with a rise in mean annual temperature, a significant increase in plant diversity and a peak in insect diversity. From fast-flying beetles to caddis flies, cockroaches and tiny, fluttering moths, an aerial predator would have had a veritable buffet of insects from which to choose. And as the only nocturnal flying predators other than owls and nightjars, bats would have had few competitors for the rich resources of the Eocene night.

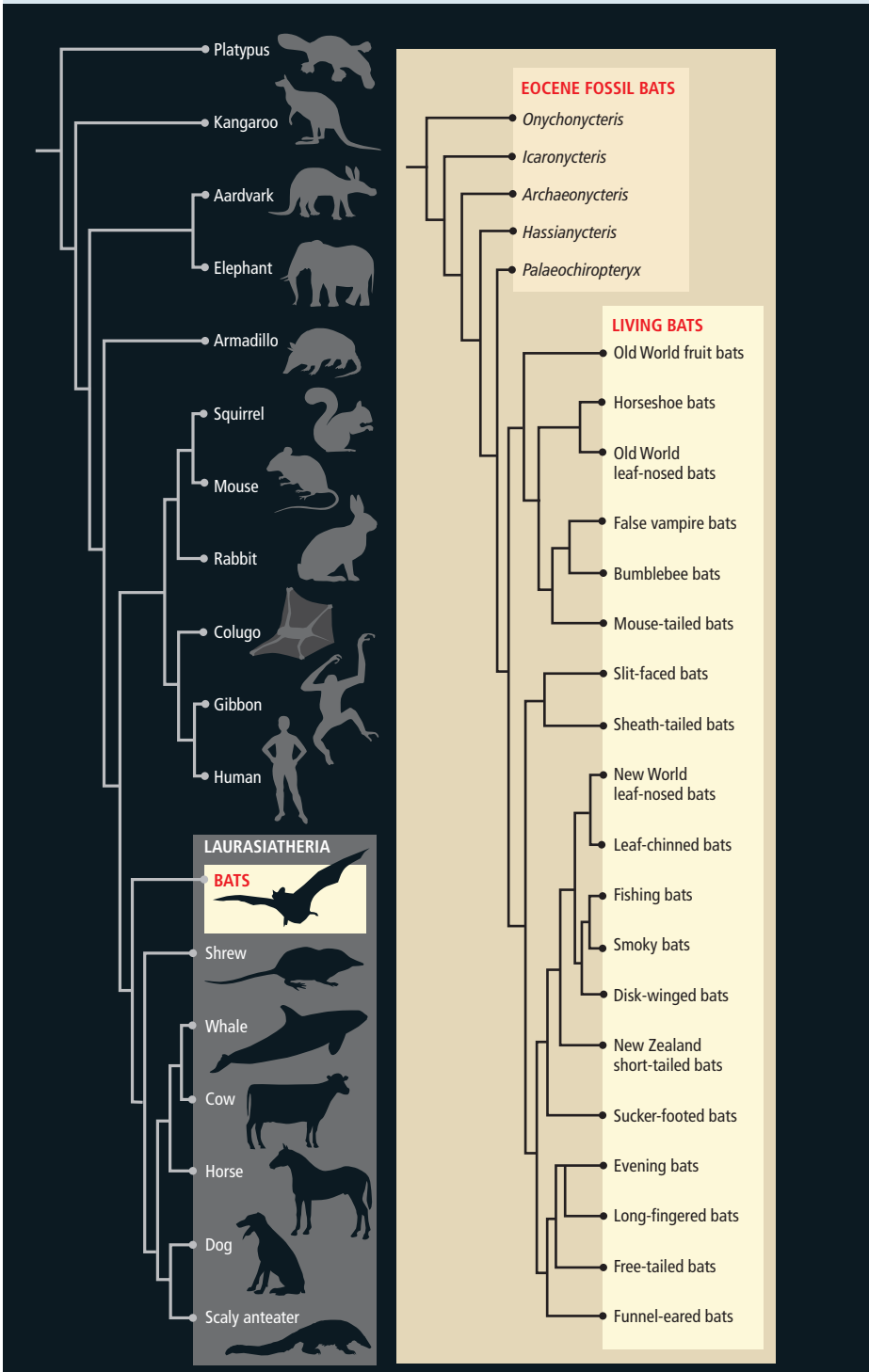
Fossils from a site called Messel in Germany provide a glimpse of this early diversification. Although at 47 million years old these fossils are only slightly younger than the bats from the Green River Formation, they are considerably more variable. Seven bat species have been found at Messel since scientific excavations began there in the 1970s, including two species of *Archaeonycteris*, two species of *Palaeochiropteryx*, two species of *Hassianycteris*, and *Tachypteron franzeni*, the oldest known member of a family of bats known as the Emballonuridae (the sheath-tailed bats) that is still alive today.

It is not hard to see why bats thrived at Messel. During the Eocene, it would have had a

[FAMILY TREE]

Putting Bats in Their Place

Biologists used to think that bats were related to either the group of small insectivorous mammals that includes shrews and their relatives or to primates and their kin—colugos among them. But recent genetic analyses have concluded that bats instead belong to a group of mammals known as the Laurasiatheria (*gray box*), which encompasses such extant creatures as dogs, whales, cows and some insectivores. (Although shrews are members of this group, bats are no closer to them than they are to the other living representatives.) The closest relatives of bats may be laurasiatheres whose lineages have gone extinct, however. To find out, researchers need to unearth fossils even closer to the origin of bats than *Onychonycteris* is.



JEN CHRISTIANSEN

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[BAT DIVERSITY]

Variation Now and Then

Modern bats are a motley crew, differing tremendously in body size, wing shape, skull form and dentition. These morphological differences reflect their divergent diets and the nature of the environments in which they forage.



INSECTIVOROUS BATS, as represented here by *Eptesicus fuscus,* tend to have long snouts and teeth with sharp, interlocking cusps, for puncturing and slicing prey. With moderately long, broad wings, it is a strong, agile flier.



VAMPYRUM SPECTRUM and other carnivorous bats are typically larger than their insect-eating cousins, although their teeth are similar. Most have short, broad wings good for maneuvering close to obstacles while hunting. As top predators, carnivorous bats are widespread but few in number.



FRUIT-EATING BATS, including *Ectophylla alba,* often have shorter faces and simpler molars than their insect- and meat-eating cousins do. They retain large canines for grasping fruit, however. Small-bodied with short, broad wings, *Ectophylla* specializes in finding small fruits in the forest understory. This bat's pale color may camouflage it when it roosts in leaf tents that the animal sculpts using its front teeth.



VAMPIRE BATS, such as this *Desmodus rotundus,* have bladelike teeth for making tiny cuts in the skin of their prey, from which they lap their blood meals. Vampires are good fliers, but they are unusual among bats in also having long thumbs and robust hind limbs that help them approach their victims by walking rather than flying.



BATS THAT SUBSIST on nectar—this *Glossophaga soricina* among them—have simplified teeth and elongated snouts that can fit inside flowers. Many possess long, extensible tongues similar to those of anteaters. Some also have specialized brushlike papillae on the tips of their tongue for extracting nectar from the base of tubular flowers. Many nectar bats are small and have short, strong wings for hovering.



The diversity evident in modern bats has ancient roots. Fossils from a site called Messel in central Germany (*map inset*) reveal that 47 million years ago, bats had already begun specializing on certain types of insect prey. The fossils at Messel preserve the stomach contents of these creatures, leaving no doubt as to what they ate. Where they foraged is less certain, but the size and shape of their wings provide a basis for speculation.



PALAEOCHIROPTERYX fed on small moths and caddis flies. With its small body and short wings, this bat likely foraged close to the ground and near vegetation, hunting from perches and hawking insects while in slow flight.



ARCHAEONYCTERIS feasted on beetles. Like *Paleochiropteryx,* this short-winged bat probably foraged near vegetation. But it may have specialized in gleaning prey from surfaces rather than catching them in the air.



HASSIANYCTERIS ate larger moths and beetles. The largest bat at Messel, it had narrow wings and was probably a fast flier that hunted in open spaces near lakes and above the forest canopy.

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balmy climate, and it was home to several lakes surrounded by lush, subtropical forest. Judging from the abundance of their fossilized remains, thousands of aerial, aquatic and terrestrial insects were available for the taking. That, in fact, is just what the Messel bats did. All seven species were insectivorous, but each one specialized in a particular subset of insects, as evidenced by their preserved stomach contents. Whereas *Palaeochiropteryx* seems to have fed on small moths and caddis flies, *Hassianycteris* apparently favored larger moths and beetles. *Archaeonycteris,* on the other hand, may have only eaten beetles. As for *Tachypteron,* no stomach contents are preserved. Yet we know it was insectivorous based on the shape of its teeth.

What did *Onychonycteris* and *Icaronycteris* subsist on? We lack the stomach contents to answer this question in detail. Insects are a good bet, though, based on the form of the bats' teeth and the wealth of insect fossils in the rocks of the Green River Formation. Most bats today subsist on insects, too. Only later in the evolutionary history of the group would some bats begin eating meat, fish, fruit, nectar, pollen and even blood.

Bat Relationships

The fossils recovered thus far from Messel and the Green River Formation have proved critical in helping researchers chart the rise of bats. Still, we lack fossils that establish how bats are related to other mammals. Tree-dwelling, gliding placental mammals known as colugos are sufficiently similar to bats that they were long thought to be close relatives. Over the past 14 years, however, Mark S. Springer of the University of California, Riverside, and others have conducted studies of DNA from large numbers of mammalian species that have shown that bats are not close relatives of any of the groups of placental mammals that include gliders such as colugos and flying squirrels. (Such creatures nonetheless offer compelling models for what the limb structure of bat ancestors might have looked like.)

Rather these genetic analyses place bats firmly in an ancient lineage known as Laurasiatheria. Other modern members of this group include such diverse beasts as carnivores, hoofed mammals, whales, scaly anteaters, shrews, hedgehogs and moles. Primitive laurasiatheres, however, were probably mouse- or squirrel-size creatures that walked on all fours and ate insects. Laurasiatheres are thought to have evolved on the ancient supercontinent of Laurasia, which comprised what is now North America, Europe and Asia, probably in the late Cretaceous period, some 65 million to 70 million years ago. The exact position of bats within this group is uncertain, but clearly a considerable amount of evolutionary change separates *Onychonycteris* and other bats from their terrestrial forebears.

Some of this change from land dweller to flier may have occurred surprisingly quickly, if recent discoveries in the field of developmental genetics are any indication. Though short by bat standards, the fingers of *Onychonycteris* are greatly elongated as compared with those of other mammals. How could this elongation have evolved?

In 2006 Karen E. Sears, now at the University of Illinois, and her colleagues reported in the *Proceedings of the National Academy of Sciences USA* that the key may lie in the activity of genes that control the growth and elongation of digits in the hand during development. Their comparisons of growth patterns in bat and mouse embryos revealed significant differences in the proliferation and speed of maturation of cartilage cells in developing fingers. A class of proteins called bone morphogenetic proteins (BMPs) plays a pivotal role in controlling these processes and in determining the length to which fingers grow. As it turns out, one of these proteins, BMP2, is produced at significantly higher levels in bat fingers than in those of mice, and manipulation of the gene that makes this protein can alter digit length. It is therefore possible that a small change in the genes regulating BMPs underlies both the developmental and evolutionary elongation of bat wing digits. If so, that might explain the absence in the fossil record of creatures intermediate between short-fingered, nonflying mammals and long-fingered bats such as *Onychonycteris* and *Icaronycteris:* the evolutionary shift may have been very rapid, and few or no transitional forms may have existed.

Despite many new discoveries about the rise of bats, mysteries remain. Bat ancestors must have existed prior to the Eocene, but we have no fossil record of them. Likewise, the identity of the closest relatives of bats is still unknown. Investigators are also eager to learn when the bat lineage first became distinct from that of the other laurasiatheres and how much of early bat evolution and diversification took place in the northern continents versus the southern continents. We therefore need fossils that lie even closer to the beginning of bats than *Onychonycteris* does. With luck, paleontologists will find such specimens, and they will help solve these and other riddles about the origins of these fascinating animals. ■

Some of the change from land dweller to flier may have occurred surprisingly quickly.

MORE TO EXPLORE

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MICHAEL DURHAM *Minden Pictures (Eptesicus fucus);* MERLIN D. TUTTLE *Bat Conservation International, www.batcon.org (Vampyrum spectrum);* MERLIN D. TUTTLE *Bat Conservation International, www.batcon.org (Ectophylla alba);* HÉLOCLIN DANIEL *Peter Arnold, Inc. (Desmodus rotundus);* MERLIN D. TUTTLE *Bat Conservation International, www.batcon.org (Glossophaga soricina);* JOHN CANCALOSI *Photo Researchers, Inc. (Palaeochiropteryx);* JACANA *Photo Researchers, Inc. (Archaeonycteris);* COURTESY OF JÖRG HABERSETZER *Senkenberg Research Institute (Hassianycteris)*

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Can Phishing Be Foiled?

Understanding the human factors that make people vulnerable to online criminals can improve both security training and technology

By Lorrie Faith Cranor

KEY CONCEPTS

- A form of online crime that lures people into giving up personal or corporate information, phishing is a growing security threat that already costs victims billions of dollars every year.
- Because phishing exploits human vulnerabilities, studying the factors that make people fall for phishing scams can improve antiphishing training and technology.
- The combined efforts of law enforcement, computer security experts and computer users are needed to reduce the success of phishing.

—The Editors

Over just a few weeks, I received e-mail messages from several banks warning me that my online banking services were in danger of being deactivated, from eBay telling me that I needed to change my password, from Apple complaining that I had unpaid bills for music downloads, from an airline offering me the opportunity to earn a quick $50 for filling out a survey and from the Red Cross asking me to contribute money to help earthquake victims in China. These messages were all very convincing and looked authentic. Except for the eBay message, however, they were all fraudulent e-mails known as "phish."

Phish e-mails are constructed by con artists to look like legitimate communications, often from familiar and reputable companies, and usually ask victims to take urgent action to avoid a consequence or receive a reward. The desired response typically involves logging in to a Web site or calling a phone number to provide personal information. Sometimes victims need only click on links or open e-mail attachments for their computers to become infected by malicious software—known as malware—that allows phishers to retrieve the data they want or take control of the victim's computer to launch future attacks. Although the details of phishing scams can vary, the result is usually the same: thousands of unsuspecting victims give information to criminals who then use it to break in to their accounts and steal their money or identities, or both.

The Anti-Phishing Working Group, an international consortium of organizations committed to wiping out Internet scams and fraud, keeps track of phishing activity, including the number of unique phishing Web sites detected every month. In 2007 monthly totals ranged as high as 55,643. During each month in 2007, anywhere from 92 to 178 different company brands were "phished"—meaning their names or logos were used to fool victims into thinking they were dealing with a trusted institution. According to research and consulting firm Gartner, an estimated 3.6 million Americans fell victim to phishing last year, leading to losses of more than $3.2 billion.

With so much at stake, the computer security community has been scrambling to develop technologies to combat phishing, such as filters for e-mail and Web browsers that flag phishing attempts. Although such software has helped stop many attacks, phishers are constantly evolving their tactics to try to stay a step ahead of such technologies. Since phishing plays on human vul-

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nerabilities—a successful attack requires a victim to succumb to the lure and take some action—it is also not strictly a technological problem. For that reason, my research group at Carnegie Mellon University is studying the best ways to teach people to recognize and avoid phishing scams. This research, in turn, is informing our design of antiphishing software so people are more likely to use it correctly. Because human factors are a critical element in the success of phishing attacks, we have found that they can be essential weapons to foil phishers as well.

Teachable Moments

When we began trying to understand why people fall for phishing attacks in 2004, my coworkers Mandy Holbrook and Julie Downs recruited people on the streets of Pittsburgh to interview. Most were unaware of phishing and assumed the term had "something to do with the band Phish." Others knew about e-mail scams that used the names of financial institutions, but they did not realize that messages seemingly from retailers might also be fraudulent. Most people had little sense of how to identify a phishing e-mail and tended to rely on superficial features, such as a logo or a professional look, to determine whether it was legitimate. They also did not understand the security messages displayed by their Web browsers and did not know how to use cues in Web addresses and within e-mail messages to judge their authenticity.

After confirming that a great need exists to educate Internet users about phishing, our next step was to review existing antiphishing training efforts to try to understand why they apparently do not work. We found a wide range of Web sites devoted to antiphishing training provided by companies, government agencies and industry associations. Some of these included a lot of technical jargon and more information than a nontechnical computer user was likely to digest. A few sites provided good background to raise awareness of the phishing threat but little in the way of actionable advice about how people could protect themselves. In fact, we found in a laboratory study that some of the best antiphishing materials in terms of raising awareness left peo-

[THE AUTHOR]



Lorrie Faith Cranor is an associate professor of computer science and of engineering and public policy at Carnegie Mellon University, where she directs the Usable Privacy and Security Laboratory and leads an antiphishing research project. She also recently cofounded Wombat Security Technologies, Inc., to commercialize products developed by her group. Cranor has published four books and scores of research papers about online privacy, phishing, spam, electronic voting, and other topics related to computer security and usability. She hopes one day people will no longer consider "usable security" to be an oxymoron.

CHAD BAKER (*computer*) AND RIKO PICTURES (*hooks*) *Getty Images*; QUINN NORTON (*Cranor*)

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Awareness of phishing in the abstract does not translate into protection, but firsthand experience with phishing could provide a powerful teachable moment.

ple overly suspicious of legitimate Web sites.

Worse still, messages that companies send to their employees or customers to warn them about phishing attacks are largely ignored. We did learn, however, that it was much easier to get research volunteers to read e-mail that looks like a phishing message than to get them to read a security-related e-mail. Our studies seemed to show, therefore, that awareness of phishing in the abstract does not translate into protection but that firsthand experience with phishing could provide a powerful teachable moment.

With some of these insights in mind, members of my team, Ponnurangam Kumaraguru, Alessandro Acquisti and others, developed a training system called PhishGuru, which delivers anti-phishing information *after* users have fallen for simulated phishing messages. The program incorporates a set of succinct and actionable messages about phishing into short cartoons, wherein a character named PhishGuru teaches would-be victims how to protect themselves. In a series of studies, we demonstrated that when people read the cartoons after falling for the simulated phishing e-mails that we sent to them, they were much less likely to fall for subsequent attacks. Even a week later our test subjects retained what they had learned. In contrast, those who read the PhishGuru cartoons sent to them by e-mail, without experiencing a simulated attack, were very likely to fall for subsequent attacks.

Extending this principle, Steve Sheng, one of my graduate students, also developed an online training game called Anti-Phishing Phil that teaches people how to identify suspicious Web site addresses while providing an experience of getting "caught" by a phisher. Players take on the role of Phil, a young fish that must examine the Web addresses associated with the worms he encounters and determine which are safe to eat. When Phil tries to bite a worm with a fraudulent address, he gets caught on a fishing hook and hauled out of the water. An older and wiser fish then appears on the scene and explains where

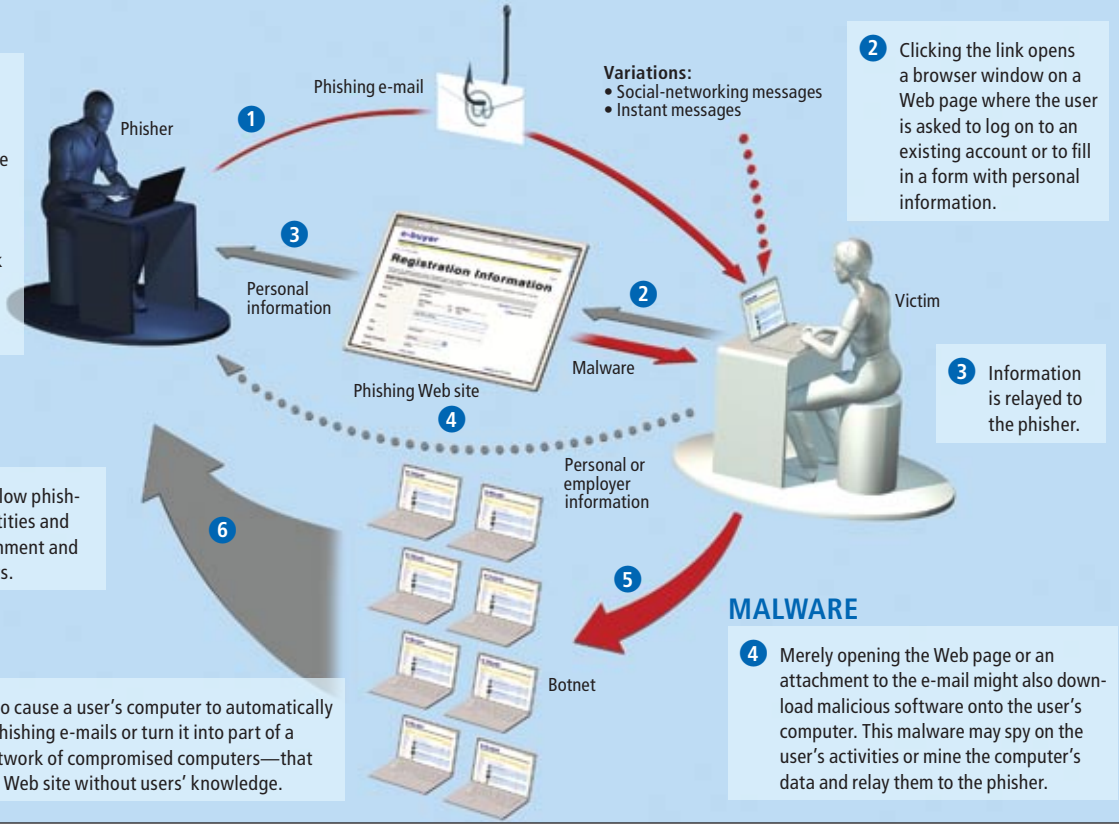
[THE BASICS]

HOW PHISHING WORKS

Phishing can take several forms, but the goal of phishers is always to lure people into giving up information by making them think they are interacting with a known and trusted company or person. Phishers are criminals seeking to profit from the information they acquire. In some cases, they also implant malicious software that controls a computer so that it can participate in future phishing scams.

THE LURE

1 Phisher sends e-mail that appears to be from a source the user trusts and urges quick action, such as clicking on a link in the e-mail or opening an attachment.



THE PAYOFF

6 Personal data allow phishers to steal identities and money or government and corporate secrets.

5 Malware can also cause a user's computer to automatically send out more phishing e-mails or turn it into part of a "botnet"—a network of compromised computers—that hosts a phishing Web site without users' knowledge.

MALWARE

4 Merely opening the Web page or an attachment to the e-mail might also download malicious software onto the user's computer. This malware may spy on the user's activities or mine the computer's data and relay them to the phisher.

GEORGE RETSECK

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[PREVENTION]

SPOTTING PHISHY E-MAIL

Phishers' preferred way to lure victims is through a mass e-mail, constructed to look like an authentic message from a well-known company. Computer users often trust such e-mails based on the presence of a familiar brand name or logo. These phishing messages do contain clues that can help identify them as fraudulent, however. Many are visible to the attentive user; others are detectable by software filters.

VISIBLE CLUES

Professional-looking design. Familiar corporate logo.

Urgent message requiring action.

Account status threat.

When cursor is held over the link, the visible address does not match underlying link shown in mail program status bar.

Subject: Wombank Urgent E-mail Verification
From: "Wombank" <creditcards@Wombank.com>
Date: Mon, November 24th, 2008 3:12 pm
To: janywhere@sciam.com
Priority: Normal
Options View Full Header | View Printable Version

WOMBANK

Dear Wombank Member,

This email was sent by the Wombank server to verify your e-mail address. You must complete this process by clicking here or on the link below and entering in the small window your Wombank User ID and Password. This is done for your protection — because some of our members no longer have access to their email address and we must verify it. For security reasons, if your account information is not verified within next 72 hours we are required by law to limit access to your account.

To verify your e-mail address and access your bank account, click on the link below. If nothing happens when you click on the link, copy and paste the link into the address bar of your web browser.

http://www.wombank.com/verifyEmail

Thank you
Accounts Management

http://www.wombank-accountonline.com/accountonline/AccountSummary.htm?verify=email

FILTER FODDER

HTML or JavaScript: Both forms of code appear in many legitimate e-mails, but phishing e-mails would be difficult to construct without them because they allow information, such as a linked address, to be hidden.

"Here" link: Phishers often use legitimate corporate links within an e-mail to lend an authentic feel, but the primary link they intend the victim to click will have a different domain address.

Domain age: A filter can search domain registries to see if the linked Web site is newly created.

Phil went wrong [*see illustration on next page*]. Through both laboratory and field studies, we have shown that the game makes a significant difference in users' ability to identify phishing sites. Comparing their performance before and after the training, we saw a drop in the number of false negatives, phishing sites mistakenly deemed to be legitimate, and false positives, legitimate sites judged to be phishing sites. The game players also outperformed participants who trained with a tutorial or with materials from other sources.

Although we have shown that we can teach people to protect themselves from phishers, even those educated users must remain vigilant and may require periodic retraining to keep up with phishers' evolving tactics. The Anti-Phishing Working Group reported that the number of programs and Web sites devoted to infecting computers with password-stealing code jumped dramatically this year, for instance. "Spear-phishing" attacks, which are tailored to their victims, are another growing trend. These can take the form of e-mails sent to the employees of a company that appear to have come from a manager in that company, leading the employees to trust the message and open its attachment. Information available on corporate Web sites and through social-networking sites can help attackers to craft these targeted messages.

Because phishers are such determined criminals, individual computer users cannot be expected to defend themselves alone. Our group also develops automatic filters that can identify likely phishing attacks. But in this work, too, we have found that human responses can be critical to a filter's success.

A Multipronged Defense

Many browser programs already include built-in security filters or can work with add-on programs for detecting suspicious Web sites. Yet even when antiphishing software tools are able to correctly identify phishing Web sites, they may still be ineffective if users choose to ignore their warnings. To understand why some people do not heed such security messages, another of my graduate students, Serge Egelman, sent simulated phishing e-mails to the volunteers participating in our research. When the recipients fell for the phishing messages and clicked on the links, warnings were triggered in their Web browsers. Egelman then found that all the participants who used the Mozilla Firefox 2 browser heeded the warnings, whereas those who used Internet Explorer 7 (IE7) often ignored them.

A high rate of false positives can undermine a filter's credibility and cause users to ignore it after a while.

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We determined that the dramatic difference in the responses of the two groups was largely attributable to the fact that the IE7 users either did not notice the warning messages or confused them with less severe warnings. Microsoft appears to have learned this lesson too, and the next generation of the Internet Explorer browser, IE8, now has clearer warning messages that are similar to those shown by Firefox.

In addition to clarity, we have found that accuracy is another critical factor affecting whether users respect the warnings of automatic filters. A high rate of false positives can undermine a filter's credibility and cause users to ignore it after a while. The antiphishing filters we tested employ a mixture of approaches to identify phishing messages and Web sites. Most commercially available tools use a blacklist of known phishing sites, for example. As new sites are reported, they are quickly added to the lists. Some tools also use a white list of known legitimate sites.

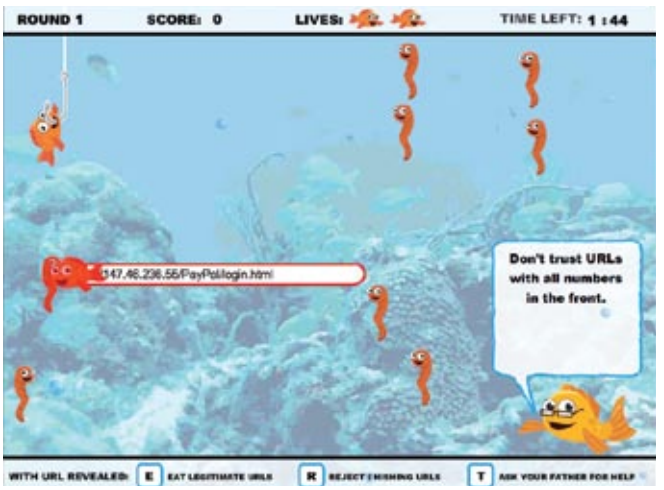
Most filters do not rely solely on such lists, however. Some analyze each Web site a user visits and apply a combination of heuristics to determine whether the site is likely to be fraudulent. A few of these are the same kinds of signals we train people to look out for, such as Web addresses beginning with all numbers or addresses that look similar to those of well-known brands. Other features the filters scrutinize include things people could not readily see; for example, the tool may take into account the age of the Web site because phishing sites are typically extremely short-lived, remaining active for as little as a few hours to days or weeks.

AVOID FALLING FOR PHISH

- Never click on a link in a suspicious e-mail or instant message, particularly one asking for personal information. If you do business with the purported sender, open your browser and type the company's usual Web address yourself.
- Look carefully at Web addresses for subtle errors, such as "Annazon.com." Learn to parse Web addresses for other clues to the site's legitimacy [*see examples below*].
- If unsure of a Web site, perform a Google search for the company. The address of the suspicious site is unlikely to appear in the top results, whereas the real company Web site will.
- See consumer tips and resources from the Anti-Phishing Working Group at: **http://apwg.org/advice**
 Play Anti-Phishing Phil at: **http://cups.cs.cmu.edu/antiphishing_phil**

The time element can make a difference in the performance of the filters that rely heavily on blacklists. Our group recently tested eight consumer antiphishing programs, for instance, by feeding them fresh phishing URLs. We discovered that most of the blacklist programs caught fewer than 20 percent of the phishing sites when we tested them within minutes of receiving the URLs. After five hours, most could detect about 60 percent of the active phishing sites. The programs that used a combination of blacklists and heuristics fared much better, with one detecting almost 90 percent of phishing attacks from the beginning of our test.

Our group has been working on programs that employ machine-learning techniques to detect phishing e-mail. This is a common approach used to detect spam e-mails, but spam detectors are not very accurate when it comes to phishing messages, which generally look legitimate. A member of our team, Norman Sadeh, has been leading an effort to develop a tool, which we originally called PILFER, that analyzes e-mails for a variety of features that may be indicative of phishing. For example, phishing e-mails often contain hyperlinked text that looks like the address of a well-known Web site, but the actual embedded computer code directs users to the attacker's site. In addition, the Web addresses in phishing e-mails often contain five or more dots and point to recently registered domain names. Not all phishing e-mails contain these features, however, and sometimes legitimate e-mails contain them as well. Researchers therefore train the program—which we have renamed Phish-





ANTI-PHISHING PHIL, an online game, teaches users to identify the addresses (URLs) of phishing Web sites by having a player take the role of a young fish named Phil that must choose to eat or reject worms associated with URLs (*left*). During and after each round, a player gets feedback on the choices and new tips (*right*). In laboratory studies, the ability of subjects who had played the game to distinguish legitimate from fraudulent URLs improved nearly twice as much as that of those trained with standard materials.

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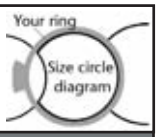
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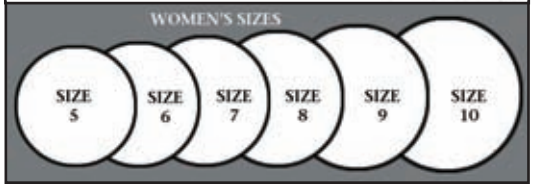
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Color	"D" Colorless	"D" Colorless
Clarity	"IF"	Clear
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[TECHNOLOGY]

FILTERING PHISH

To be effective, phishing filters need to apply criteria flexible enough to work in the face of evolving phishing tactics. A filter the author's group created to recognize phishing Web sites works with 95 percent accuracy in laboratory tests. In addition to applying some commonly used heuristics, the filter extracts a "lexical signature" of important words on the page, then performs a Google search to find a legitimate site containing those words.

HEURISTIC	SUSPECTED PHISHING CRITERIA
Age of domain	Less than or equal to 12 months
Known images	Page contains known logos but is not a domain owned by the logo owner
Suspicious URL	URL contains @ sign, hyphen, an IP address or more than five dots
Suspicious links	Link on page contains @ or hyphen
Forms	Page contains a text entry field
Lexical signature search result	URL does not match address of Google-ranked legitimate page

Patrol—by providing it with a large collection of legitimate and phishing e-mails so it can analyze these messages and learn which combinations of features are most likely to appear in phishing e-mails. In our most recent experiments, PhishPatrol was able to detect more than 95 percent of phishing messages while only triggering false positives for around 0.1 percent of legitimate messages.

We have also combined some of the features used in PhishPatrol with other approaches to detect phishing Web sites. Jason Hong has been leading our group's development of a tool called CANTINA, which analyzes the content of a Web page in combination with other heuristics to determine whether or not the page is part of a phishing site. CANTINA first employs a well-known information-retrieval algorithm to identify five terms that are important on a given Web page but relatively uncommon on the Internet overall. For example, on an eBay log-in page, this "lexical signature" might be, "eBay, user, sign, help, forgot." If you were to search for these five terms using Google, the legitimate eBay log-in page would appear among the top search results. Phishing Web sites that have replicated the eBay log-in page are unlikely to appear because one of the criteria Google's proprietary algorithm uses in ranking a Web page is the number of links to it from other pages on the Internet, so legitimate pages are more likely to be in the top results. This approach is not foolproof, however, especially if a legitimate site was recently created; thus, it is only one of several features that CANTINA considers in assessing a Web site.

The Evolving Threat

We in the computer security community are not the only ones continually seeking to improve our performance. As antiphishing technologies get better, attackers adapt their tactics. Phishing messages are now being sent via instant messenger and mobile phone text messaging. Phishers are using online games such as World of Warcraft and messaging features of social-networking sites such as MySpace and Facebook to lure their victims. Another type of phishing attack involves setting up Wi-Fi access points in public places and spoofing (imitating) the log-in pages of legitimate Wi-Fi vendors. These attacks are used to steal victims' passwords as well as to infect their computers with malware.

Organized gangs of phishers leverage thousands of compromised computers as launch points for their attacks. For instance, a group believed to be based in eastern Europe and known as the "Rock Phish gang" uses compromised computers to relay messages to phishing sites. It can thus send phishing messages that appear to originate from those computers, masking the Web address of the actual phishing site and making it difficult for law enforcement to find the real source of the attack.

Another evasive tactic this gang uses is a system that security experts have dubbed "fast-flux," in which the phishers manipulate Internet domain name servers to continuously change the numerical addresses corresponding with phishing domain names.

Phishing is only lucrative, of course, if phishers have a way of converting stolen credit-card numbers and other credentials into cash. Thus, phishers often recruit "mules" by advertising for people to fill work-from-home jobs or by befriending Internet users and convincing them that the phishers need their help. Mules are often unsuspecting victims themselves, who may believe they have been employed to perform a legitimate job. Yet a mule's real job is to transfer stolen money and to be the person who gets caught if law enforcement catches on.

By constantly improving phishing detection software and educating users about new types of phishing attacks as they are discovered, the number of phishing victims can be reduced. Coordinating international law-enforcement efforts and finding ways to make phishing less lucrative will also help. Still, phishing remains an arms race that will be hard to eliminate completely without stopping it at the source, so consumers need every form of protection they can get. ■

MORE TO EXPLORE

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Phishing and Countermeasures. Edited by Markus Jakobsson and Steven Myers. Wiley, 2007.

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Behavioral Response to Phishing Risk. Julie S. Downs, Mandy Holbrook and Lorrie Faith Cranor in *Proceedings of the 2nd Annual eCrime Researchers Summit,* pages 37–44; October 4–5, 2007.

The "Supporting Trust Decisions" Web site has information and links related to Lorrie Faith Cranor's laboratory research: **http://cups.cs.cmu.edu/trust**

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5. Being highly impressed by the results and purchasing a ROM.
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Turning Back the Cellular Clock

Shinya Yamanaka discovered how to revert adult cells to an embryonic state. These induced pluripotent stem cells might soon supplant their embryonic cousins in therapeutic promise BY TIM HORNYAK

When historians chronicle the stem cell research wars, Shinya Yamanaka will likely go down as a peacemaker. The Japanese scientist has helped send the field on a surprising end run around the moral debate surrounding embryonic stem cells, the creation of which requires the destruction of embryos. Last year Yamanaka led one of two teams that showed that normal human skin cells can be genetically reprogrammed into the equivalent of stem cells. These so-called induced pluripotent stem cells (iPS cells) seem to be essentially identical to embryonic stem cells and possess the ability to become any cell.

The 46-year-old Yamanaka is a clean-cut, almost military figure. His small office in an aging wing of Kyoto University's Institute for Frontier Medical Sciences is spotlessly tidy, with nothing to mark his achievement in producing iPS cells. A Nobel Prize may one day adorn his shelf space. As Yamanaka glances around, he remarks, "About 10 meters beneath us is a room that I have never entered. I'm not allowed to enter because I don't have permission from the government. It contains the only stem cells derived from human embryos in the country."

Though permissive in spirit, Japan in practice imposes strict rules on the production and (unlike in the U.S.) the use of stem cells derived from human embryos. Researchers can spend up to a year in paperwork submissions before gaining access to them.

It was Japan's rule-bound, often stifling scientific culture that made Yamanaka an accidental pioneer. Originally an orthopedic surgeon in Osaka, he decided in the mid-1990s to do postdoctoral work on genetic reprogramming of cancer-related genes in mice at San Francisco's Gladstone Institute of Cardiovascular Disease. There he found ready access to existing lines of embryonic stem cells, as well as an environment with solid funding and exchanges among leading researchers worldwide. At home, though, he went into a funk. "When I went back to Japan, I lost all those stimuli," Yamanaka recalls. "I had only a little funding and a few good scientists around me, and I had to take care of almost 1,000 mice by myself."

Fighting despair, he was about to quit and return to surgery. But two things galvanized him to continue: an invitation to head a small lab at the Nara Institute of Science and Technology and the creation of the first generation of human embryonic stem cells, which was made by the University of Wisconsin–Madison's James A. Thomson (who last year led the other team that produced human iPS cells).

After Thomson's achievement in isolating embryonic stem cells, many researchers began trying to control the differentiation of those cells into specific cell types that might replace diseased or damaged tissues, thereby revolutionizing clinical care. "That was too competitive for our small lab," Yamanaka recounts, "so I thought I should do the opposite—instead of making embryonic stem cells into something, I would make embryonic stem cells from something else." From Ian Wilmut's success in cloning animals such as Dolly the sheep, he says, "we knew that even completely differentiated cells can go back to an embryonic-like status. But we also thought it would be a very, very long proj-



TIM HORNYAK

SHINYA YAMANAKA

GENETIC TIME MACHINE: Put adult cells into an embryonic state with four genes. Such induced pluripotent stem cells (iPS cells) have attracted researchers hampered by restrictions on embryonic stem cells.

KEY CHALLENGES: Finding how to stop iPS cells from turning into tumors and how to create iPS cells without using retroviruses to deliver the rejuvenating genes.

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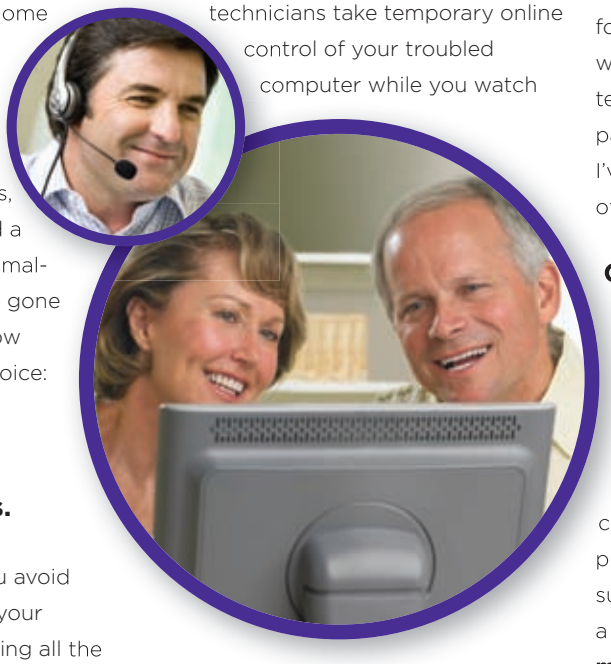
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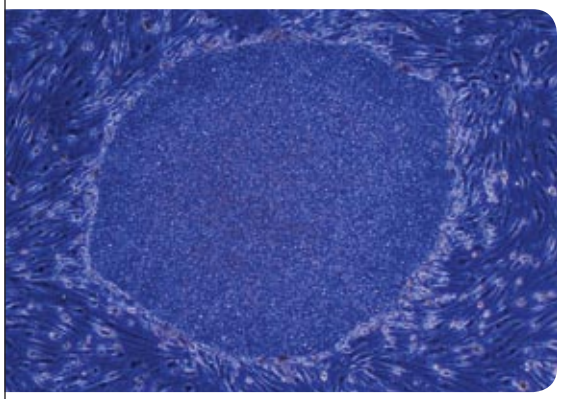
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ect," one that might take 20 or 30 years.

It took fewer than 10. Yamanaka became highly motivated to solve two main problems surrounding embryonic stem cells. One was their source. He tells of visiting a friend's fertility lab and observing early embryos under a microscope. The sight of fragile, nascent life moved him, although he emphasizes that he is not against using embryonic cells "to save patients." The other problem is the threat of immune rejection if cells derived from an embryo are transplanted into a person. Differentiated cells created from a patient's iPS cells would pose no such danger.



READY FOR ANYTHING: Circular colony of human iPS cells.

At first, then, Yamanaka set about to determine how mouse embryonic cells maintain their pluripotency, the ability to differentiate into any body cell type. He hypothesized that certain proteins would be evident in mouse embryonic cells but not in differentiated cells. He also thought that introducing the genes for these proteins—specifically, transcription factors, which control the activity of other genes—into a normal skin cell's chromosomes would transform it into an embryonic cell.

After four years of experimentation, he uncovered 24 factors that, when added to ordinary mouse fibroblast cells and subjected to the correct culturing procedures, could create pluripotent cells virtually identical to stem cells. Yamanaka kept examining each factor and found that none could do the job alone; instead a combination of four particular genes did the trick. In 2006 he published a landmark article in *Cell* identifying them: *Oct3/4*, *Sox2*, *c-Myc* and *Klf4*.

News of the stunning feat prompted scientists around the world to try to reproduce it using human, rather than mouse, cells. In 2007 Yamanaka reported that triumph with the four transcription factors at the same time as Thomson's team. "It is actually fairly straightforward to repeat what we have done," Thomson told the press at the time—still, researchers have likened the breakthrough to turning lead into gold.

The achievement sparked many investigators to switch their efforts from embryonic stem cells to the induced versions. Yamanaka and others have now derived iPS cells from a variety of tissue types, including liver, stomach and brain, and turned the iPS cells into skin, muscle, gut and cartilage, as well as neural cells that can secrete the neurotransmitter dopamine and heart cells that can beat in sync.

Two big safety issues, though, will keep iPS cells out of the clinic for a while. One is that the transcription factor *c-Myc* happens to be a powerful cancer gene, and the cells produced by Yamanaka's team tended to become cancerous. "Making iPS cells is very similar to making cancer," he explains. In principle, *c-Myc* may not be necessary: in mice, Yamanaka and a group led by Rudolf Jaenisch at the Massachusetts Institute of Technology found a way to avoid using *c-Myc*, in part, by optimizing culture conditions. Out of 100 mice implanted with iPS cells created without *c-Myc* in Yamanaka's lab, none died after 100 days, compared with six out of 100 that died of tumors when *c-Myc* was used.

The other risk is the vector used to deliver the genes into target cells—namely, retroviruses. The process results in stem cells full of viruses. Moreover, retroviruses can induce mutations in the cells that lead to cancer. Researchers may soon overcome

COURTESY OF THE INSTITUTE FOR INTEGRATED CELL-MATERIAL SCIENCES, KYOTO UNIVERSITY

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this hurdle, too. In September a team at the Harvard Stem Cell Institute announced the creation of mouse iPS cells using as a vector the adenovirus, which is safer than retroviruses. In October, Yamanaka's lab reported success using plasmids, or circular pieces of DNA. Other retrovirus alternatives include proteins and lipid molecules.

Although the surge in interest has led to rapid developments and much competition among labs, Yamanaka and others do not think that iPS cells can replace their embryonic counterparts yet. "We don't yet know if embryonic stem cells and iPS cells are truly equivalent," says Konrad Hochedlinger of Massachusetts General Hospital's Center for Regenerative Medicine. He adds that "at this point, iPS cells are a powerful additional source of pluripotent cells. Time will tell if iPS cells will at some point replace embryonic stem cells. It would be premature to make such a decision now."

But while insisting iPS cell work remains far from being clinic-ready, Yamanaka trumpets its vast potential for conditions such as diabetes, spinal cord injury, Parkinson's and even, he chuckles, baldness. "This enormous and striking finding provides a clear framework for regenerative medicine and cell therapy," says Shinichi Nishikawa, director of the Laboratory for Stem Cell Biology at Japan's RIKEN Center for Developmental Biology.

Over the next five years, Yamanaka's group of about 20 investigators will focus on how iPS cells can help predict a drug's side effects and elucidate problems in toxicology and disease mechanisms. For all the excitement, possibilities and rivalry bubbling in the wake of his findings, the one-time physician tempers his expectations with firm caution. "We still need a lot of basic research in terms of the safety of iPS cells," Yamanaka reiterates. "This is a not an international competition like the Olympic Games. It should be international collaboration. This is the beginning of a long process." ■

Tim Hornyak is based in Tokyo.

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Where on Earth You Are

By Mark Fischetti

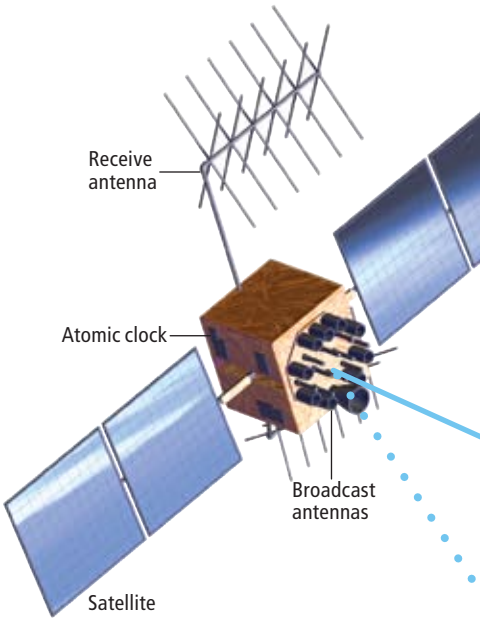
This holiday season all kinds of products are coming equipped with GPS receivers to tell consumers exactly where on earth they are. The choices include dashboard navigators for cars, pocket navigators for humans, "golf buddies" that reveal the distance between a golfer and greens and sand traps, and, most prominently, cell phones. GPS transponders also now track paroled criminals, errant pets, migrating elephants and retreating glaciers.

Positioning satellites have been beaming signals for decades, but three converging factors are broadening the marketplace, according to Per K. Enge, a professor of aeronautics and astronautics at Stanford University. The size of the circuitry needed inside a receiver has shrunk. Circuit makers are selling that hardware to consumer electronics manufacturers for less than $5 a unit. "And Apple provided visibility," Enge says, "by putting GPS into the iPhone." Buyers loved it, proving there was a desire.

As handy as personal navigators might be, their accuracy has remained within five to 10 meters for years. They will improve only after satellites surrounding the planet are upgraded. The current satellites each send a single radio-frequency signal to civilian receivers, which then combine signals from four satellites to determine position [*see main illustration*]. But the ionosphere can cause slight and random delays, introducing error into the receiver's calculations. Next-generation satellites will each send three signals at slightly different frequencies, giving receivers the data they need to cancel out the delays, resulting in accuracy of less than 50 centimeters. The first three-frequency satellite is supposed to be launched in 2009.

Do civilians need such specificity? Perhaps not, although surveyors and scientists would. More enticing, Enge maintains, are systems that work better in large cities and indoors. GPS does not perform well in these places because buildings, roofs and walls block the incoming signals. So-called hybrid, or augmented, GPS receivers, which are now beginning to be deployed, also receive broadcasts from nearby television, cell phone or Wi-Fi (for "wireless fidelity") transmitters that provide receivers with added data about position [*see illustration at bottom left*]. These broadcasts can fill urban canyons and penetrate buildings. Similarly, smaller transmitters sprinkled throughout skyscrapers will eventually solve the long-standing "problem of the vertical," which current GPS cannot do: determining not just that a visitor is at the Empire State Building, but whether he is on the seventh or 70th floor.

SATELLITES broadcast in the L-band (1 to 2 gigahertz) through antennas. At any time, up to 32 orbit the earth at about 12,550 miles (20,200 kilometers); they function until hardware fails—about 10 to 12 years—and are then replaced.



DID YOU KNOW ...

TRI AGAIN: Most colloquial descriptions of GPS say the technology uses triangulation to determine the position of a receiver on the earth. Mathematically speaking, the system uses trilateration. Triangulation determines position by measuring the angles of the triangles formed between an observer and three known points. Trilateration determines position by measuring the distance from an observer to three known points; the timing signals sent from GPS satellites (the known points) to a receiver determine those distances.

SATELLITE ENVY: More than 24 U.S. Navstar satellites make up the GPS system. Although it could provide service anywhere on the planet, some nations prefer independence. Russia has its own constellation called GLONASS; begun during the cold war, it was failing by the early 2000s but is being revived. Europe plans to complete its Galileo system by 2013. China is sending its Compass hardware aloft now. India wants to complete IRNSS by 2012—which would provide just enough satellites to cover its region. And Japan will float three satellites known as QZSS to augment GPS coverage over its territory.

HYBRID, or augmented, GPS overcomes obstructions that block regular GPS in cities and indoors. A receiver equipped with extra software senses signals broadcast by nearby television or cellular transmitters that give their exact position and combines that with any available GPS data to calculate the receiver's location. Wi-Fi transmitters can help, too.



GEORGE RETSECK

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PRODUCTS such as the personal navigators developed by Garmin (*right*) and cell phones with GPS are big sellers. The iPhone 3G (*left*) displays Google Maps images and uses GPS to locate your position, leading to turn-by-turn directions.

GPS works best across open spaces. A receiver measures the time needed for a digital code to travel from three satellites and calculates its distance from each one. The intersection of the distances determines a point on the earth's surface. Each satellite contains an atomic clock for exact timing, but receivers must make do with less accurate quartz clocks, introducing possible errors. So a receiver obtains timing data from a fourth satellite, adjusting the three range measurements.



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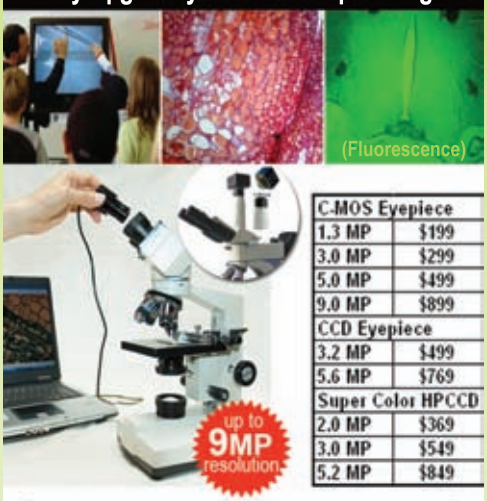
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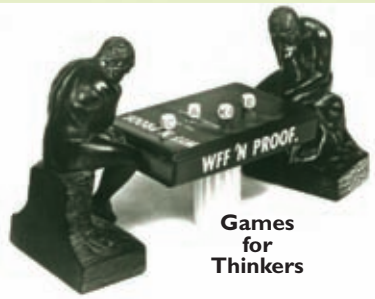
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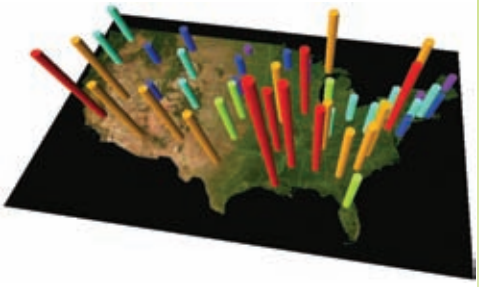
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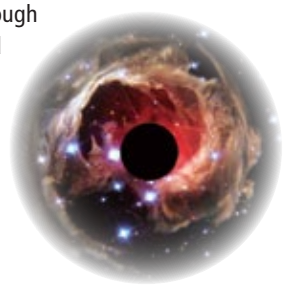
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by Bonnie J. Gisel, with images by Stephen J. Joseph. Heyday Books, 2008 ($45)
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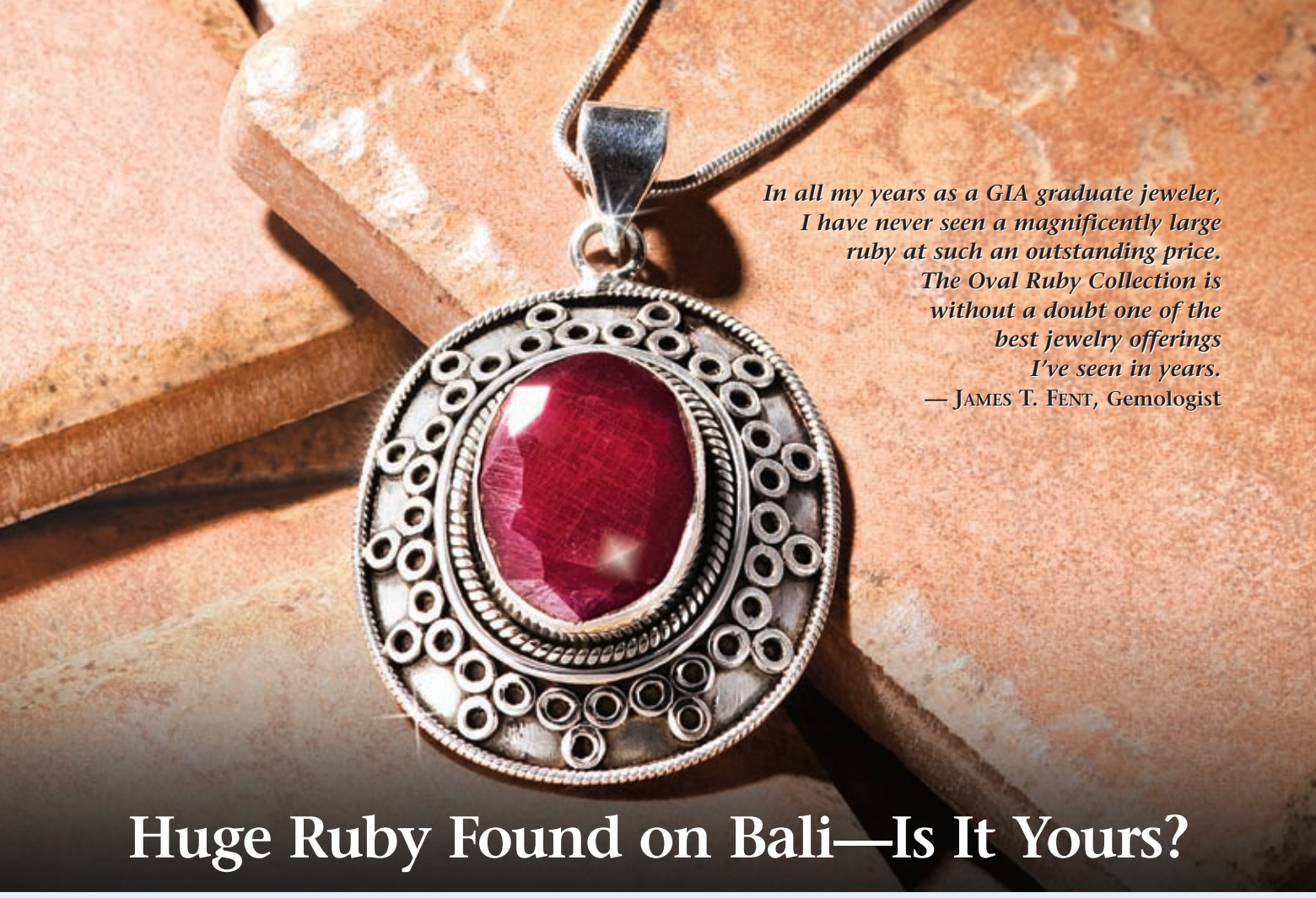
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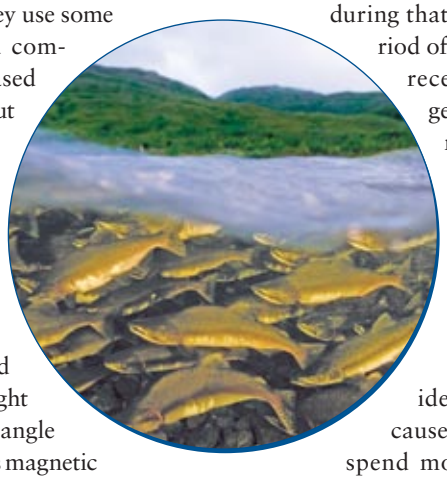
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How do **spawning fish** navigate back to the **very same stream** where they were born?

Megan McPhee, research assistant professor at the University of Montana's Flathead Lake Biological Station, steers us to an answer:

This behavior is best exemplified by salmon, which combine conventional open-water navigation and a keen sense of smell to find their way. Salmon can migrate out to sea to feed for several years before returning to spawn in the same stream, sometimes even the same section of stream, in which they were born. Other homing species probably use similar mechanisms, but few can match such precision.

How salmon return to the correct shoreline region is not completely understood. It appears they use some form of "map and compass" navigation based on information about position and direction of travel. This information most likely comes from a suite of environmental cues, including day length, the sun's position and the polarization of light that results from its angle in the sky, the earth's magnetic field, and water salinity and temperature gradients. Whatever the specific mechanism, as spawning time approaches, salmon have a seemingly inherited tendency to orient themselves toward the area of coastline where their natal waterway discharges.



We know in much more detail how they navigate after they find the river mouth. By the time salmon reach freshwater, they are guided largely by their sense of smell to the correct tributary. A series of experiments beginning in the 1950s demonstrated that young salmon become particularly sensitive to the unique chemical odors of their locale when they enter the smolt period (when they begin their downstream migration to the sea). Odors that the smolts experience during this time of heightened sensitivity are stored in the brain and become important direction-finding cues years later, when adults attempt to return to their home streams.

In one early experiment, salmon that were reared in one stream and then moved to a hatchery during the smolt stage returned to the hatchery, demonstrating the crucial role of imprinting during that transformative period of the fish's life. More recent work has suggested young salmon may go through several periods of imprinting, including during hatching and while emerging from their gravel nests.

This multistage idea makes sense because many wild salmon spend more than a year in freshwater and have moved a considerable distance through complex surroundings by the time they become smolts. In contrast, hatchery salmon imprint to a much simpler environment, which may help explain why they tend to stray (return to the "wrong" stream) more frequently than wild fish do. ■

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JOEL SARTORE *National Geographic*

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